UCRL-AR-120372 Volume II
Appendices

# DEPLETED URANIUM HEXAFLUORIDE MANAGEMENT PROGRAM

## The Technology Assessment Report for the Long-Term Management of Depleted Uranium Hexafluoride

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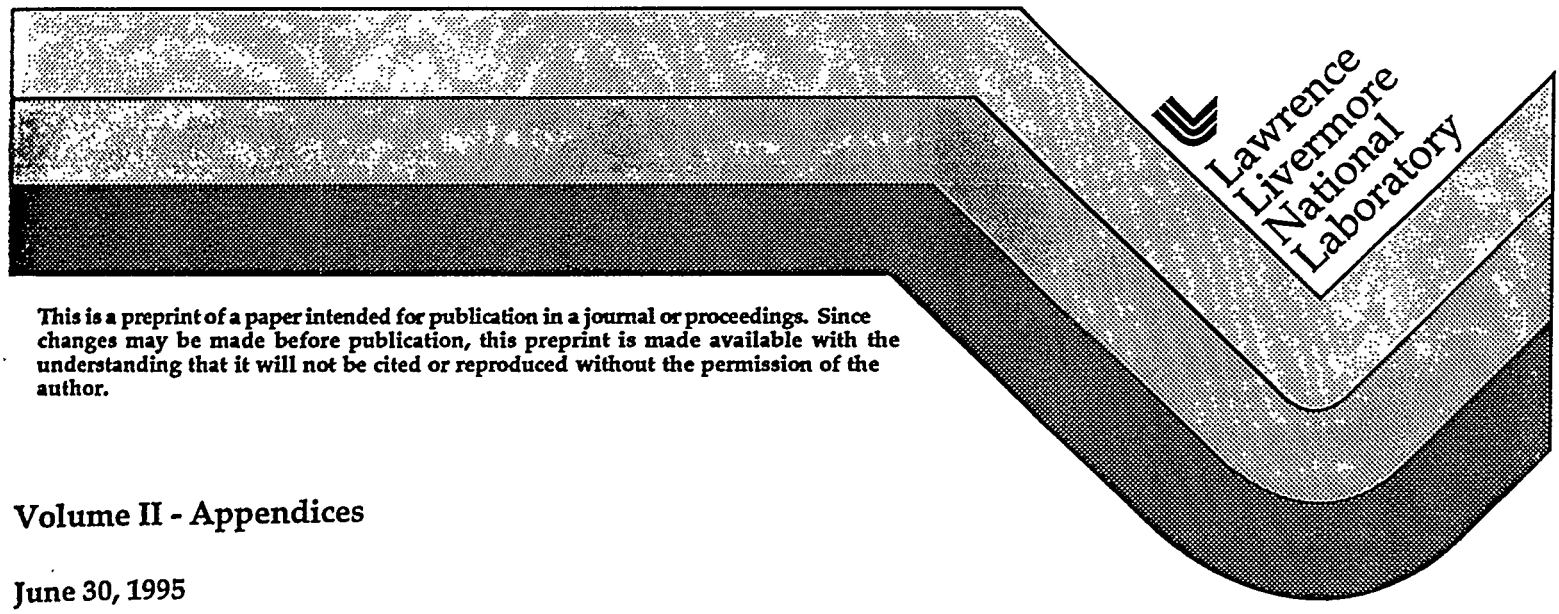




Volume II - Appendices

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Federal Register

Thursday
November 10, 1994

Part VI

# Department of Energy

Office of Nuclear Energy

Management of Depleted Uranium Hexafluoride; Request for Recommendations; Alternative Strategies for the Long-Term Management of Depleted Uranium Hexafluoride Resources at Several Geographic Locations; Notices

DEPARTMENT OF ENERGY

Office of Nuclear Energy

## Management of Depleted Uranium Hexafluoride ($UF_6$); Request for Recommendations

AGENCY: Department of Energy.

ACTION: Notice of request for recommendations.

SUMMARY: DOE is preparing to assess several alternative strategies for the long-term management or use of depleted $UF_6$. As part of that assessment, DOE is requesting recommendations from interested persons, industry, and other Government agencies for potential uses for the depleted $UF_6$ stored at the gaseous diffusion plants in Paducah, Kentucky, and Portsmouth, Ohio, and at the Oak Ridge Reservation in Tennessee, as well as for technologies that could facilitate the long-term management of this material.

DATES: Individuals or organizations wishing to make recommendations should do so in writing by December 12, 1994, to ensure their consideration.

ADDRESSES: Please submit recommendations to Mr. Charles E. Bradley Jr., Office of Uranium Programs, Office of Nuclear Energy, U.S. Department of Energy, 19901 Germantown Road, Germantown, MD 20874.

SUPPLEMENTARY INFORMATION:

### 1. Background

Uranium is a naturally-occurring radioactive element containing different isotopes, notably Uranium-238 (U-238) and Uranium-235 (U-235). The usability of uranium for controlled fission in nuclear chain reactions in most nuclear reactors depends on increasing the proportion of the U-235 isotope in the material through an isotopic separation process called enrichment. This process divides a stream of $UF_6$ into separate streams—one enriched in U-235 and the other depleted in U-235. The first large scale enrichment process was developed by the United States through the Manhattan Project in the 1940s. The process of enrichment used in the United States is called "gaseous diffusion," and has continued under the auspices of the Atomic Energy Commission and its successor agencies, including DOE. On July 1, 1993, general responsibility for uranium enrichment was transferred from DOE to the United States Enrichment Corporation (USEC).

Gaseous diffusion was developed, on a large scale, first at the Oak Ridge Reservation in Tennessee and, later, at plants located near Paducah, Kentucky, and Portsmouth, Ohio. Using $UF_6$ as feed material for the enrichment process, these plants produced highly enriched uranium for defense needs of the United States, as well as low enriched uranium for use as fuel in commercial nuclear reactors. The production of highly enriched uranium was discontinued in 1992 due to the reduced requirements of the U.S. defense programs. All diffusion operations at the Oak Ridge facility ceased in 1985.

A major consequence of the gaseous diffusion process is the accumulation of a significant amount of depleted $UF_6$. This material is so named because it is depleted in the percentage of the U-235 isotope, as compared to the original feed material. Most of this material is stored at the Paducah and Portsmouth Gaseous Diffusion Plants and at the Oak Ridge Reservation. The total amount in storage at these three sites is approximately 560,000 metric tons. Depleted $UF_6$ is a solid at ambient temperatures, and is stored in large cylinders holding approximately 14 tons each, stacked two layers high, which are subject to regular inspection and maintenance. About 29,000 cylinders are stored at Paducah, 13,000 at Portsmouth, and 5,000 at Oak Ridge.

2. DOE is publishing, elsewhere in today's Federal Register, an Advance Notice of Intent (ANOI) to prepare an EIS on alternative strategies for the long-term management of depleted $UF_6$. The first step in the process to consider alternative approaches is this Request to the public, industry, and other Government agencies for information and suggestions for potential uses for depleted $UF_6$ and/or technologies that could facilitate the long-term management of the material. This Request will help to ensure that the resulting long-range management strategy will consider all reasonable alternatives. For purposes of responding to this Request, current regulatory requirements should not be considered a barrier to recommended uses or technologies. DOE will evaluate each submission to determine if it should be included as a reasonable alternative in the EIS, which will assess the environmental impacts of the various alternative management strategies.

3. DOE requests from the public, industry, and other Government agencies, their suggestions and recommendations on the following:

A. *Uses or applications of products or materials that use any form of depleted uranium.* Such uses or applications could be for the depleted uranium in its current chemical form, for any of its individual components, for either the uranium or fluorine in some other chemical or physical form, or products made from any form or compound of depleted $UF_6$ including alloys, cements, or other materials. Suggested uses and applications should not be limited to those that only DOE or another Government agency might pursue. The Department is interested in all possible uses or applications for the depleted $UF_6$, whether by the public or the private sector. With the suggestions, the Department requires as much of the following information as possible:

1. A description of the use or application, including a design description and/or flow sheet; material, fabrication, product, and other specifications; and resulting wastes or effluents;

2. The potential annual and total usage;

3. The technical status of the use or application (that is, whether it is standard industrial practice; demonstrated on a bench or small scale, but not on an industrial scale; engineering, materials, or design development needed; etc.);

4. Facilities, equipment, other materials, and labor required;

5. Environmental and health and safety approvals required;

6. Any Government participation or funding required;

7. Estimated cost, including research, development and demonstration; construction; operations; decontamination; decommissioning; basis for estimates; and assumptions; product value, if any; and

8. Proposed schedule including, research, development and demonstration; and operations.

B. *Technologies that could facilitate the long-term management of the depleted uranium.* The Department requires as much of the following information as possible concerning the recommended technology:

1. The environmental, health and safety, and economic characteristics;

2. A description of the technology and any processes or treatment, including a design description and/or flow sheet; material, fabrication, product, and other specifications; and resulting wastes or effluents;

3. The status of the technology and any required research, development or demonstration;

4. Materials balance information and chemical composition of any wastes produced;

5. Labor requirements for both construction and operation;

6. Timing of research, development and demonstration; construction; and operation;

7. Factors that might limit siting choices;

8. Facilities, equipment, or materials required; and

9. Estimated cost, including research, development and demonstration; construction; operations; product value, if any; decontamination; decommissioning; basis for estimates; and assumptions.

4. If any of the information supplied to the Department is proprietary, privileged and confidential commercial or financial information, a trade secret, or otherwise exempt from public disclosure, it should be so designated and the Department will protect this information in accordance with its standard procedures as prescribed in 10 CFR 1004.11 or other applicable law. The title page of the information should be marked with the restriction cited in the regulation. Each page to be so restricted should be marked with the following legend:

Use or disclosure of data contained on this sheet is subject to the restriction on the title page.

5. A DOE Laboratory will prepare a report, based on evaluations by independent experts, on the responses to the request for recommendations. After review of the laboratory report, responses DOE considers reasonable will be included as alternatives for which environmental impacts will be assessed in the EIS. DOE will also initiate a study of the life cycle costs of each EIS alternative. That study will also be considered, along with the final EIS, when DOE selects a strategy from among these alternatives.

6. This Request is solely for the information described above and is not for the purpose of obtaining recommendations and/or proposals for research, development, and demonstration to be funded by the Government.

7. Except as provided in paragraph 4, the written submissions from the public, industry, and other Government agencies will be made available for public review at DOE Public Reading Room located in Room 1E–190 at 1000 Independence Avenue SW, Washington, DC 20585.

8. Throughout this process, opportunities for public participation will be provided to discuss technologies submitted. Comments will be requested on the criteria that the technical experts will use to evaluate responses to this Request for Recommendations.

9. In addition to the ANOI, DOE intends in the future to publish in the Federal Register, a notice of intent to begin the scoping process for the preparation of the EIS on the selection of a strategy for the long-term management of the depleted uranium hexafluoride.

Issued in Washington, D.C. on this 26th day of October, 1994.

Terry R. Lash,

*Director, Office of Nuclear Energy.*

[FR Doc. 94–27781; Filed 11–9–94; 8:45 am]

BILLING CODE 6450–01–P

## Alternative Strategies for the Long-Term Management of Depleted Uranium Hexafluoride Resources at Several Geographic Locations

**AGENCY:** Department of Energy.

**ACTION:** Advance notice of intent to prepare an environmental impact statement.

**SUMMARY:** The Department of Energy is providing advance notice of its intent to prepare an environmental impact statement pursuant to the National Environmental Policy Act of 1969 (NEPA). The environmental impact statement will assess the potential environmental impacts of alternative strategies for the long-term management or uses of depleted uranium hexafluoride ($UF_6$) resources currently stored at Paducah, Kentucky; Portsmouth, Ohio; and Oak Ridge, Tennessee.

This environmental impact statement will consider general strategy options, including the general impacts of siting potential facilities or transporting materials to or from such facilities. In addition, such analyses would focus on those issues that would affect strategy selection, such as consolidation at one site. The specific environmental impacts of the transportation of materials or impacts from the actual siting of any projects that would result from strategy selection would be further assessed by any necessary project NEPA documents to follow.

**DATES AND ADDRESSES:** The Department of Energy requests comments by January 9, 1994, but comments sent after that time will be considered to the extent possible. The anticipated date for the formal notice of intent is June 1995. The dates and locations of all scoping meetings will be announced in that notice of intent or subsequent Federal Register notices as well as in local media, prior to the planned meetings.

Written comments on the scope of the environmental impact statement, questions concerning the proposed action, and requests for copies of referenced material should be directed to: Mr. Charles E. Bradley Jr., Office of Uranium Programs, Office of Nuclear Energy, United States Department of Energy, 19901 Germantown Road, Germantown, Maryland 20874, (301) 903–4781.

**FOR FURTHER INFORMATION CONTACT:** For general information on the Department of Energy NEPA review process, please contact Ms. Carol M. Borgstrom, Director, Office of NEPA Oversight, United States Department of Energy, 1000 Independence Avenue, S.W., Washington, D.C. 20585, (202) 586–4600 or 1–800–472–2756.

**SUPPLEMENTARY INFORMATION:** Depleted $UF_6$ is stored as a solid compound of uranium and fluorine in large cylinders. It is produced by an enrichment process that divides a single stream of $UF_6$ into two separate streams—one enriched in uranium-235 and one depleted in uranium-235. The enriched $UF_6$ is withdrawn from the process and used to produce fuel for commercial nuclear power plants: The depleted $UF_6$ is withdrawn from the process and stored in large cylinders.

The purpose of the environmental impact statement is to assess the potential impacts of a range of technological or market options related to the management of depleted $UF_6$ (currently stored at Paducah, Kentucky; Portsmouth, Ohio; and Oak Ridge, Tennessee), including use, reuse, conversion, or disposal, and to select a strategy for the long-term management of such depleted $UF_6$ in light of the changed missions and functions. Should the Department of Energy develop any proposal in the future to use any fraction of the depleted $UF_6$ inventory for its own research or other activity, that proposal would be the subject of a separate NEPA document, and would not affect this notice.

The environmental impact statement will focus on the Department of Energy's depleted $UF_6$ stored at the Paducah, Portsmouth, and Oak Ridge sites. Other forms of depleted uranium (e.g., uranium oxides and uranium metal) and depleted $UF_6$ used or stored at other sites would not be analyzed in the environmental impact statement since they exist only in small quantities (taken all together they total about 7 percent of the quantity of the subject depleted $UF_6$), would not affect strategy selection, and would involve different management and potentially different uses. Should the Department propose an action that involves these other forms of depleted uranium, such a proposal would receive appropriate NEPA review.

The Department of Energy is publishing elsewhere in today's Federal Register a Request for Recommendations for potential uses for the depleted $UF_6$, which includes a request for suggestions of technologies that could facilitate the long-term management of the material. The request will also be published in industry and trade publications.

The Department of Energy intends to use technical experts to evaluate the responses that are received from the requests. Following the Department's receipt of the technical evaluations, the Department will determine which responses evaluated are reasonable and include them as alternatives to be assessed in the environmental impact statement. The Department will provide opportunities for the public to participate in the technology evaluation process. The Department will also initiate a separate study on the costs of the depleted $UF_6$ uses and management options assessed in the environmental impact statement. This request to the public, industry, and other Government agencies is the first step in the process to consider alternative approaches. The request and the evaluations that follow will help to ensure that the resulting long-range management strategy will consider all reasonable alternatives.

The Department of Energy will also initiate a study of the life cycle costs of each environmental impact statement alternative. That study will also be considered, along with the final environmental impact statement, when the Department selects a strategy from among the reasonable alternatives.

## Invitation To Comment

The Department of Energy intends to conduct a full and open process to define the scope of the environmental impact statement and is issuing this Advance Notice of Intent as a preliminary step in seeking public comment on the proposed action, the range of alternatives, and the scope of impact analysis. Written comments from all interested parties are invited in order to assist the Department in defining the scope of the environmental impact statement, including the identification of the likely alternatives and significant environmental issues. Written comments should be sent to the address shown at the beginning of this notice.

Following the completion of this preliminary public comment period, the Department of Energy will publish a notice of intent to initiate the scoping process, including the schedule of public meetings to receive oral or written comments on the scope of this environmental impact statement. At this time, the Department is not scheduling any public meetings in advance of the notice of intent. If there is significant interest in holding earlier public meetings, however, the Department will consider any requests and would publish notices for such meetings prior to holding them.

## Background

Uranium is a naturally-occurring radioactive element containing different isotopes, notably Uranium-238 and Uranium-235. The ability to use uranium for controlled fission in nuclear chain reactions in most nuclear reactors depends on increasing the proportion of the Uranium-235 isotope in the material through an isotopic separation process called enrichment. This process divides a single stream of $UF_6$ into two separate streams—one enriched in Uranium-235 and the other depleted in Uranium-235. The first large-scale enrichment process was developed by the United States through the Manhattan Project in the 1940s. The enrichment technology employed in the United States is called "gaseous diffusion," which has continued under the auspices of the Atomic Energy Commission and its successor agencies including the Department of Energy. On July 1, 1993, general responsibility for uranium enrichment in the United States was transferred from the Department to the United States Enrichment Corporation.

Gaseous diffusion was developed, on a large scale, first at the Oak Ridge Reservation in Tennessee and later at plants located near Paducah, Kentucky, and Portsmouth, Ohio. Using $UF_6$ as feed material for the enrichment process, these plants produced highly enriched uranium for the defense needs of the United States, as well as low enriched uranium for use in making fuel for commercial nuclear power reactors. All diffusion operations at the Oak Ridge facility ceased in 1985, and that facility is awaiting decontamination and decommissioning.

The Energy Policy Act of 1992 established the United States Enrichment Corporation as a new Government corporation which generally has responsibility for enriched uranium production at the Portsmouth and Paducah plants, as well as United States marketing rights for enriched uranium produced or blended at those plants. The United States Enrichment Corporation is leasing the plants from the Department of Energy, has signed an agreement for division of responsibilities between the Department and the Corporation at the two plants, and assumed responsibility for enriched uranium production on July 1, 1993. All depleted $UF_6$ created beginning July 1, 1993, is the responsibility of the Corporation. Consequently, the proposed Department strategy for depleted $UF_6$ management does not include material created after July 1, 1993; however, the Department's decisions on depleted $UF_6$ disposition could affect the Corporation's operating plans and policies. The environmental impact statement will include a discussion of the likely impacts of any of the Department's decisions on the Corporation, but cannot commit to a course of action for material controlled by the Corporation without prior agreement. Public comment on the scope of possible actions and agreements is welcome.

A major consequence of the gaseous diffusion process is the accumulation of a significant amount of depleted $UF_6$. Most of this material is stored at the Paducah and Portsmouth Gaseous Diffusion Plants and at the Oak Ridge Reservation. The total amount of depleted $UF_6$ stored at these three sites is approximately 560,000 metric tons. Depleted $UF_6$ is stored in large steel cylinders holding approximately 14 tons each, stacked two layers high, in large "yards" at the sites. The cylinders are inspected regularly to detect and repair any leaks should they occur. About 29,000 cylinders are stored at Paducah, 13,000 at Portsmouth, and 5,000 at Oak Ridge.

Potential uses of depleted $UF_6$ and its chemical constituents include: (1) use of uranium metal in armament manufacture or as metal or oxide-based shielding in the management of radioactive materials, including wastes or spent nuclear fuel; and (2) use of hydrogen fluoride, hydrofluoric acid, and fluorine for commercial industrial processes.

## Purpose of the Environmental Impact Statement

The purpose of the environmental impact statement is to evaluate the impacts of alternative strategies for the long-term management and use of depleted $UF_6$ stored at the Paducah, Portsmouth, and Oak Ridge sites. Such alternatives would be analyzed for their impacts on the human environment, including risks to public health and safety, occupational health and safety, and effects upon the natural environment. The need for the proposed action arises from changes in various domestic and international factors. These factors include: the changed mission and functions of the Department of Energy programs for nuclear materials production and

research; changes brought about by the end of the Cold War; the shift in emphasis mandated by the President's budget requests; and by directives of the Secretary of Energy to reconsider future Department missions, functions, and responsibilities. The unique properties and value of depleted $UF_6$, as well as the large volumes in storage, suggest that the evaluation, analysis, and decisions on the fate of this material be made separate from those of other materials in storage or awaiting disposition. The Department has determined that such an action is a major Federal action with potentially significant environmental impacts and requires the preparation of an environmental impact statement in accordance with NEPA. This environmental impact statement will aid in making management decisions on depleted $UF_6$ by evaluating the environmental impacts of a range of reasonable alternatives, as well as providing a means for a public voice in the decision-making process. The Department is committed to ensuring that the public has a full and complete opportunity to be heard on this matter and is providing this advance notice of intent to that end.

**Preliminary Description of Alternatives for Environmental Impact Statement**

The Department of Energy requests public input on all relevant aspects of the long-term management and use of depleted $UF_6$ and potential alternatives. At this time, the Department has no preferred alternative and will consider for inclusion in the environmental impact statement all reasonable alternatives. The following is a discussion about the preliminary list of alternatives for the environmental impact statement that may be modified by additions or deletions; public comment on the range of alternatives is hereby requested.

*Continue Current Storage and Management Practices (NO ACTION)*

This alternative would continue present storage and management practices for depleted $UF_6$ at the Paducah, Portsmouth, and Oak Ridge locations for at least twenty to thirty years, until shutdown and decommissioning of the facilities. At this time, the depleted $UF_6$ at the Department of Energy's Paducah, Portsmouth, and Oak Ridge facilities is stored in steel cylinders the specifications for which are typically: a capacity of 14 tons, a diameter of 48 inches, a length of 12 feet, and wall thickness of 5/16 inch. There are approximately 47,000 such cylinders in storage at the three sites (29,000 at Paducah, 13,000 at Portsmouth, and 5,000 at Oak Ridge).

Current management practices consist of: (1) use of special equipment to transport cylinders within the storage yards; (2) regular visual inspection of all cylinders to verify cylinder integrity; (3) replacement/refurbishment of deteriorating cylinders, as necessary; (4) construction/reconstruction of cylinder storage yards, as necessary; (5) operating procedures for control of radioactive and hazardous material exposure to workers and for response to any unanticipated releases of depleted $UF_6$; (6) restacking of cylinders when needed to facilitate inspections, and replacing wood "saddles" (storage chocks) with concrete saddles; (7) technical assessments of cylinder performance and development of improved inspection methods; and (8) research on coatings to apply to cylinder surfaces to control corrosion.

*Modifications to Depleted $UF_6$ Storage Facilities and Procedures*

This alternative would include significant changes in the Department of Energy's facilities and management procedures for depleted $UF_6$ in storage. Such changes could consist of one or more of the following:

(1) redesign of the storage yards to add diking and runoff collection;

(2) construction of storage buildings in lieu of outdoor storage;

(3) provision of double-walled containers for the cylinders; and

(4) increased inspection frequency.

*Use of Depleted $UF_6$*

This alternative would consist of a number of sub-alternatives for depleted $UF_6$ use by means of conversion through chemical processes that separate the uranium from the fluorine. Likely end products could be uranium oxide, calcium fluoride, depleted uranium metal, depleted uranium concrete, hydrogen fluoride or hydrofluoric acid, the latter having commercial value in industrial processing. Locations for such conversions could include one or more of the following: (1) Department of Energy facilities where depleted $UF_6$ is stored; (2) One or more commercial nuclear fuel fabrication plants or industrial facilities in the United States; or (3) Commercial nuclear facilities outside of the United States. The analysis of this alternative would include the results of feasibility studies of each subalternative, as well as a discussion of the relative impacts of each subalternative.

Use of the converted depleted $UF_6$ would be evaluated as subalternatives including: (1) use as radiation shielding in the management of nuclear materials including waste and spent nuclear fuel, and (2) use in armament manufacture.

*Disposal of Depleted $UF_6$*

This alternative would consist of the analysis of potential impacts from the disposal of depleted $UF_6$ either in its present form, or in other forms, at appropriate waste disposal facilities.

*Identification of Environmental Issues.* The impact analysis would consider, for each alternative, the health and safety risks to workers and to the public of material transportation, storage, and use, as well as any potential impacts to environmental resources. As to the site-specific impacts of technologies, the analyses would be generic rather than site-specific for any technology alternative; selection of a site is not part of the proposed Department of Energy action and will be preceded by appropriate NEPA documentation. The environmental impact statement would provide estimates of the maximum impacts expected.

*Related and Other Department of Energy NEPA Documentation.* Should the depleted $UF_6$ strategy selection result in site-specific actions, additional NEPA documents would be prepared to consider the specific impacts on the site and vicinity from any proposed action. Such analyses would address site-specific issues such as historic resources, threatened and endangered species, critical environmental resources, floodplain, and land use.

The Draft and Final Environmental Impact Statements on the Alternative Strategies for the Long-Term Management of Depleted Uranium Hexafluoride Resources at Several Geographic Locations, and related documents, will be available for inspection, when completed, at the Department of Energy's Freedom of Information Reading Rooms. The location of these Reading Rooms will be announced in the Notice of Intent to prepare an environmental impact statement.

Issued in Washington, D.C., this 21st day of October, 1994.

Peter N. Brush,

*Principal Deputy Assistant Secretary, Environment, Safety and Health.*

[FR Doc. 94-27780; Filed 11-9-94; 8:45 am]

BILLING CODE 6450-01-P

## FINAL EVALUATION FACTORS

The following are the final evaluation factors given to the Independent Technical Reviewers, with specific issues to be considered with each factor.

**Environment, Safety, and Health.** Consider the following issues of concern to workers, the public, and the environment:

1. *Issues that may arise as a result of operations, transportation, handling, storage, and disposal, including effluents and emissions.*

2. *Issues that may restrict site choices when constructing or operating a facility that employs this technology or application.*

3. *Design configurations, specifications, or operational requirements that pose problems of nuclear, chemical, or other safety issues involving workers or the public.*

**Waste Management.** While this factor might well be included in the Environment, Safety, and Health factor, its potential significance deserves special attention.

1. *Radiological, nonradiological, hazardous, toxic, mixed, or solid waste streams and waste volumes, or residual material that may pose problems of storage, transportation, treatment, or disposal.*

2. *Potential for waste minimization in use or manufacture.*

3. *Potential for recycling.*

**Costs.** Consider costs that are associated with the development or use of a technology or product, or that could preclude consideration of a recommendation.

1. *Capital costs, both initial (including R&D) and continuing.*

2. *Annual operating and maintenance costs.*

3. *Decontamination and decommissioning costs.*

4. *Value of any product or facility salvage.*

5. *Cost avoidance through sale of any byproducts.*

**Technical Maturity.** For technologies or uses that have no prior history, estimate the time-to-availability. Consider the probability of success. Which of the following developmental stages describes the technology:

1. *Design - conceptual or detailed.*
2. *Bench or small scale.*
3. *Developed but untested on a large scale.*
4. *Tested or used on a large scale, but not standard industrial practice.*
5. *Standard industrial practice.*

**Socioeconomics.** Consider the effects of the application of a product or the use of a management technology on the following:

1. *Employment.*
2. *Public acceptance.*
3. *Local or regional development.*

**Other factors.** Add any other information believed pertinent to the feasibility of the submission.

Lawrence Livermore National Laboratory

FISSION ENERGY AND SYSTEMS SAFETY PROGRAM

November 28, 1994

Dr. Mary English
University of Tennessee
327 South Stadium
Knoxville, Tennessee 37996

Dear Dr. English:

The U. S. Department of Energy has recently announced its intention to assess alternative strategies for the long-term management or use of depleted uranium hexafluoride (see enclosed *Federal Register* notices).

In support of this action, Lawrence Livermore National Laboratory is assisting the Department of Energy by having independent technical reviewers evaluate proposed uses or management technologies for the material. Evaluation factors are being developed as guidelines for the reviewers conducting the assessments. A draft of the evaluation factors is enclosed for your review and comment.

Please submit comments for consideration in developing these evaluation factors to the address below by January 9, 1995. Comments received after this date will be considered, if it is practical to do so. For additional information, please feel free to call (301) 916-6666.

Sincerely,

Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

SEP:ewm

Comments are shown on the attached. Thanks for the chance to look this over.

M. English

English
12/22/94
Comments

Where practical, please limit your evaluations to 300 words for each factor.

## II. Evaluation Factors

**A. Environment, Safety, and Health.** Consider the following issues of concern to workers and the public:

1. Issues that may arise as a result of operations, transportation, handling, storage, and disposal, including effluents and emissions.

2. Issues that may restrict site choices when constructing or operating a facility that employs this technology or application.

3. Design configurations, specifications, or operational requirements that pose problems of nuclear, chemical, or other safety involving workers or the public.

4. Issues that may restrict future use opportunities in areas surrounding our LLNL site.

**B. Waste Management.** While this factor might well be included in Factor A, its potential significance deserves special attention.

1. Radiological, nonradiological, hazardous, toxic, mixed, or solid waste streams and waste volumes that may pose problems of storage, transportation, treatment, or disposal.

2. Potential for waste minimization in use or manufacture.

3. Potential for recycling.

**C. Costs.** Consider costs which are associated with the development or use of a technology or the use of a product, or which could preclude consideration of a recommendation.

1. Capital costs, both initial and continuing.

2. Annual operating and maintenance costs.

3. Decontamination and decommissioning costs, and radioactive waste disposal capacity requirements

4. Value of any product or facility salvage.

5. Cost avoidance through sale of any byproducts.

D. **Technical Maturity**. For technologies or uses that have no prior history, estimate the time-to-availability. Consider the probability of success. Which of the following developmental stages describes the technology:

1. Design - conceptual or detailed
2. Bench or small scale
3. Developed but untested on a large scale
4. Standard industrial practice

E. **Socioeconomics**. Consider the effects of the application of a product or the use of a management technology on the following:

1. Employment
2. Public acceptance
3. Local or regional development

F. **Other factors**. Add any other information believed pertinent to the feasibility of the submission.

**Department of Energy**

Oak Ridge Operations
P.O. Box 2001
Oak Ridge, Tennessee 37831—

January 19, 1995

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, Maryland 20874

Dear Mr. Scott:

Reference is made to your letter dated January 11, 1995, thanking Wayne Hibbitts for his recent comments concerning the evaluation factors that are being used as guidelines for assessing proposed uses and long-term management strategies for depleted uranium hexafluoride. Mr. Hibbitts retired from the Oak Ridge Operations Office on January 3, 1995. I appreciate your offer to send Mr. Hibbitts updated newsletters and notices, but as he is no longer working for the Department of Energy, please remove his name from your mailing list. Thanks!

Sincerely,

Virginia Parker

Virginia Parker, Secretary
to the Assistant Manager
for Environment, Safety, and Quality

**Department of Energy**

Oak Ridge Operations
P.O. Box 2001
Oak Ridge, Tennessee 37831—

December 1, 1994

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

Dear Mr. Patton:

COMMENTS ON DRAFT EVALUATION FACTORS FOR DEPLETED URANIUM ALTERNATIVES ASSESSMENTS

The draft factors appear to be straight forward and largely complete. I suggest the following minor additions:

- In section A. "Consider the following issues of concern to workers, the public, and the environment:"
- In section D. "5. Tested or used on a large scale, but not standard industrial practice."
- In Section E. "4. Foreclosure of future uses of the depleted uranium."

Thank you for the opportunity to review your proposal.

Sincerely,

H. Wayne Hibbitts
Deputy Assistant Manager
for Environment, Safety, and Quality

# CENTRAL SOUTHEAST OHIO ASSOCIATION

OHIO CONFERENCE UNITED CHURCH OF CHRIST

4041 NORTH HIGH STREET • SUITE 301 • COLUMBUS, OHIO 43214-3200

ROGER MILLER, *Association Minister*
ALAN N. McLARTY, *Associate Association Minister*
DONNA JEAN BLANEY, *Administrative Secretary*

614/267-5411 OR 800/282-0740 (In Ohio) FAX 614/267-3181


December 5, 1994

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., Second Floor
Germantown, MD 20874

Dear Mr. Patton,

Thank you for the invitation to participate in the development of the evaluation factors relative to the long-term management or use of depleted uranium hexafluoride. I will seek comments and forward any received per your instructions.

Grace and Peace,

Roger Miller
Association Minister
RM/djb

**Department of Energy**
Oak Ridge Field Office
P.O. Box 2001
Oak Ridge, Tennessee 37831—

December 6, 1994

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Boulevard, Second Floor
Germantown, Maryland 20874

Dear Mr. Patton:

EVALUATION FACTORS FOR DEPLETED URANIUM HEXAFLUORIDE MANAGEMENT PROGRAM

In response to your November 28, 1994, letters to me; Mr. Joe La Grone, Manager, Oak Ridge Operations; and Mr. Jim Hall, Assistant Manager for Energy Research and Development, I offer the following comments regarding the evaluation factors that will be used by the technical reviewers in evaluating proposed uses or management technologies for depleted uranium hexafluoride.

In the **Waste Management** section, you should state that this section should include any byproduct or residual material. Also, one of the evaluation subfactors in this section should be the utilization of material in inventory (specifically, the amount of material expected to be utilized).

In the **Costs** section, costs for the storage (including any surveillance and maintenance activities) should be included. Also, one of the evaluation subfactors in this section should be the costs associated with research and development needed for any new/proposed technologies (those with no prior history).

In the **Socioeconomics** section, one of the evaluation subfactors in this section should be the effect of any anticipated procurements.

Finally, a question was raised in the public meeting in Oak Ridge as to how the Department will evaluate the use of some part (or all) of the material as an energy source. This question needs to be addressed in the evaluation factors.

If you have questions or would like to discuss this further, please let me know. I can be reached at (615) 576-0892.

Sincerely,

Joe W. Parks
Assistant Manager for
Enrichment Facilities

909 West Outer Dr
Oak Ridge, TN 37830
6 December, 1994

Dear Mr. Patton:

I recently received a letter from you concerning evaluation factors for the Uranium Hexafluoride Program. I read this with interest and considerable confusion. What, exactly, are you seeking? Comment on your evaluation factors - like what other considerations would I suggest? Or what considerations would I delete?

Another point escaped me - why me? I have had no experience with uranium hexafluoride. Or does this matter?

Was something perhaps omitted from the package you sent?

Very truly yours,

Herman Weeren

USEA
United States Energy Association



1620 Eye Street, NW
Suite 1000
Washington, DC 20006
Tel: (202) 331-0415
Fax: (202) 331-0418

December 8, 1994

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

Dear Mr. Patton:

Thank you for sending us your letter of December 1 announcing your intention to assess alternative strategies for the long-term management or use of depleted uranium hexafluoride.

We appreciate your thinking of us; however, we do not believe this is an appropriate endeavor for the United States Energy Association to undertake at this time.

Again, thanks and please keep us on your mailing list.

Sincerely yours,

John Rasmussen, D.Sc.
Director, Government Programs

JR/pc

OFFICE OF THE SECRETARY

# UNITED STATES INTERNATIONAL TRADE COMMISSION

WASHINGTON, D.C. 20436

December 8, 1994

Mr. Scott Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd. 2nd Floor
Germantown, MD 20874

Dear Mr. Patton:

Thank you for your letter of November 28, 1994, to Mr. Brookhart requesting an evaluation by the Commission of uses and management technologies for depleted uranium hexafluoride to assist the Department of Energy in assessing alternate strategies for the long-term management or use of this material.

We regret that we cannot provide such assistance. Such an evaluation is beyond our expertise. Our agency is primarily a fact-finding agency that is involved in studying the impact of imports on domestic industries and in providing upon request, advice to the Congress and the President on tariff and trade matters.

Please continue to call on us whenever we can be of assistance.

Sincerely,

Donna R. Koehnke

Donna R. Koehnke
Secretary

14 Nov

John Taylor (Sandia) ✓
Balance Programs
505 844 8207

$UF_6$

review evaluation factors

Comments

Specifically –

National Security considerations used

concern might be used for
Pu production

Safeguarding concerns
fissile materials ??

Policy Implications NN-41

other factors

Technical Maturity / nuclear
~~export~~ disposal only?

THE UNIVERSITY OF TENNESSEE
INSTITUTE OF AGRICULTURE

Department of Animal Science
P. O. Box 1071
Knoxville, TN 37901-1071
(615) 974-7286
FAX: (615) 974-7297

December 15, 1994

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

Dear Mr. Patton:

Enclosed are my comments and suggestions on evaluation for the depleted hexafluoride management program. I appreciate the copy of Federal Register, dated November 10, 1994 which helped guide me in this review.

My comments were somewhat restricted to my areas of research in mineral nutrition and radiation biology.

Sincerely,

Carl

M. C. Bell, Ph.D.
Professor Emeritus

/jf
Enclosure
Copy to: Mr. Charles E. Bradley, Jr.

**Recommendations for Management of**
**Depleted Uranium Hexafluoride**
**by M. C. Bell**

**Evaluation Factors**

A. Environment, Safety and Health

Uranium is widely distributed in our environment and is usually in concentrations not hazardous to health and safety. Uranium is not an element which is an essential nutrient for animals and plants. Fluoride is an essential element necessary to reduce dental cavities and bone diseases. Fluorides are also widely distributed in nature and usually are not in concentrations hazardous to health of plants and animals. Fluorine is a very reactive element and it is potentially the most hazardous part of the depleted $UF_6$.

B. Waste Management

1. Depleted uranium would not be a significant health hazard if properly handled. The alpha emissions pose no external hazard and since less than 0.1% is absored, it is no hazard in the food chain to humans. In contrast fluorine is very reactive, toxic and readily absorbed by plants and animals.

2. Potential for recycling is excellent. Depleted $UF_6$ should be processed and recycled. Use of uranium metals are many. In addition to the many uses of fluorides in industry, it is very essential in nutrition to reduce cavities and bone diseases. It is added to most water supplies at the rate of 1 p.p.m. to replace the fluoride taken out by water purification procedures. Using $^{18}F$ labeled fluoride, Bell et al (1961) showed that fluoride was quickly incorporated into both maternal and fetal bones and teeth of cattle. Fluorides are incorporated into teeth and bone as calcium fluoro phosphate apatite crystals. Most foods and livestock feeds average about 7 p.p.m. fluoride on a dry matter basis, but excess fluoride is very toxic (Hobbs et al, 1954). It appears to be wasteful to continue to store depleted uranium hexafluoride when there is so much potential to safely use uranium and fluorides.

C. Costs

Costs should be kept to a minimum by using realistic proven processing procedures which have been successfully used in working with $UF_6$ preparation. Decontamination should not be to levels below those occurring in nature. All byproducts should be sold to reduce costs. Competitive private enterprise bids should be sought. Processers such as Allied Chemical Co.., who prepared $UF_6$ from oxides of uranium should be well qualified to reverse the process.

D. Socioeconomics

Public acceptance of fluorides is already in existance with the many uses of fluorides, including being added to toothpaste and water. Uranium radioactivity risks might easily be compared with annual background and with what the average person gets from annual medical diagnostic tests, which range from low exposure for chest X-rays to high exposures for CT scans.

With the taxpayers funding over 220 billion each year to pay interest on the national debt, this should not be a pork barrel project. The most efficient, least expensive, most practical and safest way should be used to accomplish the use of depleted $UF_6$.

**Literature Cited**

Bell, M. C., G. M. Merriman and D. A. Greenwood. 1991. Distribution and excretion of $^{18}F$ fluoride in beef cattle. J. Nutr. 73:368-385.

Hobbs, C. S. et al. 1954. Fluorosis in Cattle and Sheep. TN Agr. Exp. Sta. Bulletin 235, 163 pages.

**FLUOR DANIEL**

Fluor Daniel, Inc.
3333 Michelson Drive, Irvine, CA 92730
(714) 975-3889 Fax: (714) 975-4793

**Dwayne Wilson**
Government Services

December 21, 1994

Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

Dear Mr. Patton

Long-Term Management
of Depleted Uranium Hexafluoride

In response to your request for comment to the evaluation factors for long-term management of depleted uranium, Fluor Daniel has submitted its recommendation directly to Mr. Charles Bradley at DOE Germantown office.

If you require a copy of our response, please call me at (714) 975-3889.

Sincerely,

Dwayne A. Wilson
Director, Business Development

DAW.lc

DAW12.21

**Department of Energy**

Oak Ridge Operations
P.O. Box 2001
Oak Ridge, Tennessee 37831— 8739
December 22, 1994

Mr. Scott E. Patton
FESP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd. 2nd Floor
Germantown, MD 20874

Dear Mr. Patton:

**EVALUATION FACTORS FOR DEPLETED URANIUM HEXAFLUORIDE MANAGEMENT PROGRAM**

**Reference: Your letter for Peter Gross dated November 28, 1994.**

As per your request, we have examined the proposed evaluation factors to be used by independent technical reviewers in evaluating proposed uses and management technologies for DOE's inventory of depleted uranium hexafluoride. We suggest adding to the Waste Management evaluation factor: maintaining the present cylinder storage option coupled with a cylinder maintenance until the middle of the next century . By then it should be apparent if there is likely to be a sufficient demand for depleted uranium to exhaust the amount in storage in the cylinders. Based on studies done by the Oak Ridge Operations Office, the cylinders can be maintained as storage vessels until 2050 if they are sandblasted, painted, and stored on concrete cradles so that they are not in contact with the ground. To prematurely convert the uranium hexafluoride to another form or disposal of it before there is ample opportunities for uses for it to develop, could be very wasteful.

Any questions should be directed to W. D. Dillow at (615) 576-1354.

Sincerely,

for Peter J. Gross, Director
Environmental Protection Division

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
800 NORTH QUINCY STREET
ARLINGTON, VA 22217-5660

IN REPLY REFER TO
Ser 03B/30
22 Dec 94

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

Dear Mr. Patton:

I am responding to your letter of 28 November 1994 to Captain R. A. Burnett requesting comments on draft evaluation factors to assess alternative strategies for the long term management or use of depleted uranium hexafloride. Although Captain Burnett recently rotated to another command, I am happy to provide a response based on discussions with appropriate experts within the Office of Naval Research.

In our judgement, the draft evaluation factors are satisfactory, without modification, for the purposes outlined in the enclosures that accompanied your letter. The draft factors provide an adequate framework to ensure coverage of all important considerations and flexible enough to avoid focusing evaluators on a narrow set of issues.

Thank you for the opportunity to comment.

Sincerely,

BRUCE B. ROBINSON
Deputy Director
Science and Technology Directorate

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

23 December 1994

Mr. Scott E. Patton
FESSP Washington Operations, Lawrence Livermore National Laboratory
20201 Century Blvd.
Germantown, MD 20874

Dear Mr. Patton

We have reviewed your evaluation factors for the Depleted Uranium Hexafluoride Management Program. We find the factors to be sufficient, complete, and satisfactory in every manner. We are also satisfied that all of the factors will be given an equal weighting.

Thank you for providing us the opportunity to coordinate on your program.

Sincerely

ROBERT E. COCHOY, Colonel, USAF
Deputy Director
Science & Technology

Tennessee Valley Authority, 1101 Market Street, Chattanooga, Tennessee 37402-2801

Oliver D. Kingsley, Jr.
President, TVA Nuclear and Chief Nuclear Officer

December 27, 1994

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Boulevard, 2nd Floor
Germantown, Maryland 20874

Dear Mr. Patton:

Tennessee Valley Authority (TVA) appreciates the opportunity to review the proposed evaluation factors for the Depleted Uranium Hexafluoride Management Program.

The five factors proposed appear to adequately consider the impacts of the strategies on the environment, safety, health, waste management, costs, and socioeconomics. We believe that these factors are sufficient to perform comparative evaluations of the various options proposed to handle the depleted uranium hexaflouride stockpile.

Sincerely,

O. D. Kingsley, Jr.

Lawrence Livermore National Laboratory

**Evaluation Factors for**
**Depleted Uranium Hexafluoride Management Program**

**November, 1994**

Lawrence Livermore National Laboratory has been contracted by the Department of Energy to identify uses or technologies that could be considered in selecting a long-term management strategy for depleted uranium hexafluoride. This task is to be accomplished by having independent technical reviewers assess whether or not a proposed use or technology is reasonable. Evaluation factors are being developed as guidelines for conducting the assessments, and are intended to give the reviewer a sense of the issues important to the Department of Energy. The draft evaluation factors are attached for your review and comment.

More information on the Department of Energy's Depleted Uranium Hexafluoride Management Program and the evaluation factors can be found in the following recently published notices:

Management of Depleted Uranium Hexafluoride ($UF_6$); Request for Recommendations (*Federal Register*, Vol. 59, No. 217, November 10, 1994, pg. 56324)

Alternative Strategies for the Long-Term Management of Depleted Uranium Hexafluoride Resources at Several Geographical Locations (*Federal Register*, Vol. 59, No. 217, November 10, 1994, pg. 56325).

Please submit comments by January 9, 1995 to the address below. If you have any questions, please call (301) 916-6666.

Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

This document is too broad. I recommend to enter location analysis and location section (see item F).

Amir Gamliel
Ph.D., P.G., Senior hydrologist.

Next time, Please provide a business return envelop.

**DRAFT**

# Evaluation Factors for Independent Technical Reviewers: Depleted Uranium Hexafluoride Management Program

November, 1994

## I. Review Instructions

The following factors are to be applied in evaluating proposed uses and management technologies for the Department of Energy's inventory of depleted uranium hexafluoride. Management technologies include any technologies that could be used in the storage, handling, transportation, conversion/transformation, or disposal of the material. These factors are based on the *Federal Register* notice of November 10, 1994 (Vol. 59, No. 217), in which the Department requested recommendations and asked that respondents provide as much information as possible on various aspects of the use or technology being recommended.

Reviewers should evaluate each response on its own merits, and not in comparison to other alternatives or recommendations. The factors listed below should be viewed as guidelines, rather than as a formula by which to score the recommendations. The list of factors is intended to give the reviewer a sense of the issues which are important for enabling the Department of Energy to determine whether the recommendation is reasonable or not. The reviewer should particularly seek to identify and discuss issues that may not be evident to nonexperts. The reviewer should also note recommendations which are of particular merit.

Evaluations should be qualitative in nature and based on judgment born of the reviewer's special expertise and experience. Opinions should be clearly and substantially supported. Evaluations need not address every item in the list of factors if the reviewer believes that not all are relevant in each case. Moreover, the absence of a factor from the list below should not be taken to mean that the factor is not important. In such a case, the reviewer should indicate the factor at issue, justify its inclusion, and include it in the evaluation.

Feasibility is a relative concept in this undertaking. A recommendation may not, in the end, be determined to be "reasonable" if it is only "feasible" under highly restrictive conditions. Where appropriate, include consideration of the probability of success within a reasonable time period. The reviewer's professional judgement is particularly important in such matters, especially where an inherent advantage of a recommendation is so significant that it merits special consideration with regard to "time to technical maturity."

Although the *Federal Register* notice instructed respondents to ignore regulatory restrictions, existing or likely, when recommending a use or technology, regulatory considerations are important in judging whether a recommendation is feasible or not. Should a response be of particular merit, however, the Department may wish to consider seeking to change the regulation.

Where practical, please limit your evaluations to 300 words for each factor.

## II. Evaluation Factors

**A. Environment, Safety, and Health.** Consider the following issues of concern to workers and the public:

1. Issues that may arise as a result of operations, transportation, handling, storage, and disposal, including effluents and emissions.

2. Issues that may restrict site choices when constructing or operating a facility that employs this technology or application.

3. Design configurations, specifications, or operational requirements that pose problems of nuclear, chemical, or other safety involving workers or the public.

**B. Waste Management.** While this factor might well be included in Factor A, its potential significance deserves special attention.

1. Radiological, nonradiological, hazardous, toxic, mixed, or solid waste streams and waste volumes that may pose problems of storage, transportation, treatment, or disposal.

2. Potential for waste minimization in use or manufacture.

3. Potential for recycling.

**C. Costs.** Consider costs which are associated with the development or use of a technology or the use of a product, or which could preclude consideration of a recommendation.

1. Capital costs, both initial and continuing.

2. Annual operating and maintenance costs.

3. Decontamination and decommissioning costs.

4. Value of any product or facility salvage.

5. Cost avoidance through sale of any byproducts.

D. **Technical Maturity**. For technologies or uses that have no prior history, estimate the time-to-availability. Consider the probability of success. Which of the following developmental stages describes the technology:

1. Design - conceptual or detailed
2. Bench or small scale
3. Developed but untested on a large scale
4. Standard industrial practice

E. **Socioeconomics**. Consider the effects of the application of a product or the use of a management technology on the following:

1. Employment
2. Public acceptance
3. Local or regional development

F. **Other factors**. Add any other information believed pertinent to the feasibility of the submission.

Location:

1. Tectonics
2. Surface water
3. G.W.
4. erosion
5. proximity to populated area
6. Proximity to water resources (human & animals)
7. cost of alternative locations.

WESTERN KENTUCKY UNIVERSITY

Department of
Engineering Technology

Bowling Green, KY 42101
502-745-2461

January 3, 1995

Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century BLVD., 2nd Floor
Germantown, MD 20874

Dear Mr. Patton:

I have reviewed the list of evaluation factors to be used by independent technical reviewers in evaluating proposed uses and management technologies for depleted uranium hexafluoride. I believe the list to be sufficiently comprehensive to support a full exploration of issues concerning the management alternatives. The only possible area of concern not explicitly included would be a consideration of infrastructure requirements. Such concerns could be addressed under one or more of the other broad categories.

Sincerely,

John P. Russell

John P. Russell

WESTERN KENTUCKY UNIVERSITY

Department of
Engineering Technology

Bowling Green, KY 42101
502-745-2461

January 3, 1995

Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century BLVD., 2nd Floor
Germantown, MD 20874

Dear Mr. Patton:

I have reviewed the list of evaluation factors to be used by independent technical reviewers in evaluating proposed uses and management technologies for depleted uranium hexafluoride. I believe the list to be sufficiently comprehensive to support a full exploration of issues concerning the management alternatives. The only possible area of concern not explicitly included would be a consideration of infrastructure requirements. Such concerns could be addressed under one or more of the other broad categories.

Sincerely,

John P. Russell

John P. Russell

MARTIN MARIETTA

'ARTIN MARIETTA ENERGY SYSTEMS, INC.

POST OFFICE BOX 2003
OAK RIDGE, TENNESSEE 37831

January 4, 1995

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

Dear Mr. Patton:

**Depleted Uranium Hexafluoride ($DUF_6$) Alternative Strategies for Long-Term Management**

In response to your November 28, 1994, letter, the following are comments addressing the draft evaluation factors for independent technical reviews of depleted uranium hexafluoride management proposals solicited by the Department of Energy (DOE) in its November 10, 1994, *Federal Register* notice.

While the evaluation factors appear to "cover the bases" and are intended to be used qualitatively, its not clear how one would determine which proposals if any should not be forwarded to DOE for the Environmental Impact Statement (EIS) alternatives selection process. These appear to be the right factors for rating a proposal, but seem to lack the characteristic of "must factors" for determining which proposals make the initial cut.

I have circulated the factors among the site environmental coordinators and have received no other specific comments.

Sincerely,

Conard L. Stair

Conard L. Stair, Deputy Director and
Environmental Compliance Program Manager

CLS:TPAP:ss

cc: V. C. Huffstetler (B.1.b.8)
T. P. A. Perry
File
EC Doc. Ctrl. - RC

Central and South West Services, Inc.

1616 Woodall Rodgers Freeway
P.O. Box 660164 • Dallas, Texas 75266-0164
214-777-3705

RICHARD P. VERRET
President, Production Services

January 4, 1995

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Boulevard, 2nd Floor
Germantown, Maryland 20874

Dear Mr. Patton:

Central and South West Corporation is pleased to see positive steps underway by the Department of Energy to effectively disposition the stored depleted UF6 which has accumulated as a result of our nation's defense program and commercial nuclear reactor program. We applaud the effort you and the Lawrence Livermore national Laboratory have started to identify uses or management technologies for depleted UF6.

As requested by your letter of November 28, 1994, we have reviewed the draft evaluation factors proposed as guidelines for assessing alternative strategies. While the evaluation factors appropriately cover key considerations at a high level, we believe additional detail guidance and standards will be necessary to achieve the desired level of consistency in the technical reviews.

Two specific comments are offered for your consideration. First, the area of public acceptance is so important it should be a separate high level factor. Public acceptance currently is a sub item in the socioeconomic category. Second, the waste management factor should be expanded to incorporate the potential combination of depleted UF6 with other waste forms which would resolve multiple concerns with one process.

CSW appreciates the opportunity to provide comments early in the process of addressing this important issue. If we can be of further assistance, please let us know.

Sincerely,

RPVpm

*Fay M. Martin, PhD,* **(615-241-3340)**
ORNL Health Studies Agreement Program Manager
101 Midway Lane, MS-6481
Oak Ridge, TN 37830

January 4, 1995 (Wednesday)

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

Dear Mr. Patton,

I have examined the evaluation factors and I think all the fields have been adequately covered.
I would give emphasis to the alternative which supports the "Use of Depleted UF6 and its Chemical Constituents". From this alternative, the management technologies for the following uses should be given great consideration:

1) Use of converted depleted UF6 as radiation shielding in the management of nuclear materials including waste and spent nuclear fuel
2) Use of converted depleted UF6 in armament manufacture
3) Use of hydrogen fluoride, hydrofluoric acid, and fluorine for commercial industrial processes.

I think the other alternatives are not as beneficial, that is:
a) The NO ACTION alternative - Continue current storage and management practices
b) Modifications to depleted UF6 storage facilities and Procedures, and
c) Disposal of depleted UF6.

The Evaluation Factors (EF) that I consider most important are:

1) EF A. Environment, Safety and Health. Special attention should be given to safety problems involving workers or the public because this is the area from which most controversy will arise.
2) EF C. Costs. This is also important with the recent discussions in budget trimming. Thus the proposal should present cost sheets showing profits expected from the above-mentioned uses.
3) EF E. Socioeconomics. This is important in that if jobs can be created in a region, this lends to acceptability of a program.

I am impressed with the background work that has gone into this project. I hope to be kept informed of the outcome.

Sincerely,
Fay M. Martin
Fay M. Martin

Nuclear Fuel Services, Inc.
P.O. Box 337, MS 123
Erwin, TN 37650

(615) 743-9141

January 5, 1995

Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Boulevard, 2nd Floor
Germantown, Maryland 20874

Dear Mr. Patton:

**Reference:** **Request for input related to evaluation factors for $UF_6$ management strategies, dated, 11/28/94.**

With this letter I am providing an additional evaluation factor per the reference as follows:

F. Conservation. Consider that both the uranium and fluorine present in $UF_6$ are natural resources and that substantial energy has been invested to form the fluorine and $UF_6$. Therefore consider the effectiveness of candidate technologies to do the following:

1. Conserve the fluorine and uranium as natural resources in useful forms.

2. Conserve (as much as practical) the energy input to form the $UF_6$.

Best wishes for a successful project.

Sincerely,

Allen M. Vaughan
Director Process Technology
Sales and Marketing

AMV/ksr

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

January 5, 1995

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

Dear Mr. Patton:

Thank you for your letter to Mr. Bernero, dated November 28, 1994, concerning evaluation factors to be applied in the assessment of uses or management technologies for depleted uranium hexafluoride. In your letter you request comments on the proposed evaluation factors. In the staff's opinion, the draft evaluation factors encompass the major categories necessary to properly assess the proposed uses and management technologies. It is suggested that the following additional guidelines would aid the reviewers in providing a complete evaluation:

Section A. Environment, Safety, and Health.

4. Issues that may present conflict between short term and long term concerns (e.g. immediate disposal versus conversion to a useful product and later disposal.)

Section C. Costs.

6. Cost reduction through large volume processes.

7. Cost reduction by use of existing facilities or structures (e.g. conversion to $U_3O_8$ for disposal in existing mine shafts.)

Section F. Other Factors.

1. Degree of compliance with existing regulations.
(Note: this is mentioned in the instructions to the reviewer but is not included in the draft evaluation factors.)

2. Estimated time required for implementation.

If you need any further clarification, please feel free to contact Tom Wenck of my staff at (301) 415-8088.

Sincerely,

Robert F. Burnett, Director
Division of Fuel Cycle Safety
and Safeguards, NMSS

GENCORP
AEROJET

Charles W. Montford
Director, Contract Administration

P O Box 399
Jonesborough, TN 37659

Tel: 615-753-1200
Fax: 615-753-8645

05 January 1995

Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

Subject: Request for Recommendations (RFR) for Depleted Uranium Hexafluoride ($dUF_6$) Management Program

Dear Mr. Patton:

In response to the subject RFR, Aerojet Ordnance Tennessee (AOT) and Babcock & Wilcox (B&W) are herewith submitting a summary of our recommendation. This summary describes the AOT/B&W Team's understanding of the Department of Energy's $dUF_6$ management program, the Team's program related experience, and potential product lines for the $dUF_6$.

Not later than 17 February, AOT/B&W will respond specifically to the six (6) Evaluation Factors contained in the Lawrence Livermore National Laboratory publication of 15 November 1994.

If you have any questions about the AOT/B&W summary response to the RFR, please contact the undersigned.

Sincerely,

Charles W. Montford
Director, Contract Administration

cc: Mr. Robert A. Cordani
Director
Uranium Processing and Services
Babcock & Wilcox
Naval Nuclear Fuels Division
P.O. Box 785
Lynchburg, VA 24505-0785

Mr. Charles E. Bradley, Jr.
Environmental Manager
Facility Technology and
Management Division
Office of Uranium Programs
Office of Nuclear Energy
U.S. Department of Energy
19901 Germantown Road
Germantown, MD 20874

Enclosure

**OAK RIDGE NATIONAL LABORATORY**
MANAGED BY MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE U.S. DEPARTMENT OF ENERGY

POST OFFICE BOX 2008
OAK RIDGE, TENNESSEE 37831-6023

January 6, 1995

Mr. Scott E. Patton
Lawrence Livermore National Laboratory
Fission Energy and Systems Safety Program
20201 Century Boulevard, Second Floor
Germantown, Maryland 20874

Dear Mr. Patton:

**Review of Draft Evaluation Factors for Independent Technical Reviewers: Depleted Uranium Hexafluoride Management Program, November 1994**

The set of Evaluation Factors proposed are highly appropriate to the task and should be retained, as is. However, it may be prudent to augment these as follows:

1. Schedule:
- Time to startup.
- Time to work off inventory.

Rationale--The factors Cost and Technological Maturity do not capture essential elements related to schedule optimization. Differences in development and/or implementation times (i.e., time to availability) are only one part of the equation. Some technologies may not be cost effective at high throughputs, requiring protraction of the schedules (e.g., increased work-off times)--and possibly increased ES&H risks associated with protracted storage, etc..

2. Technical Feasibility:
- Operability.
- Long-term effectiveness or reliability.

Rationale--The "probability of success" is too open-ended as a criterion. A technology may "work" but may require extensive (and expensive) maintenance, periodic outages, etc., compared to another technology which is not only more operable and reliable but more robust in terms of the final product/form.

3. Flexibility:
- Phased approach to development and implementation.
- Ability to accommodate a range of final waste management options (products, forms).

Rationale--In today's resource-constrained world, development and implementation of technologies may have to be coupled (phased) in order to be cost- and schedule-effective and to work off depleted uranium hexafluoride inventories in an optimum fashion. That is, we may be forced to accept some risks and use a learn-as-we-go approach. Thus, options that can be deployed more

rapidly and begin to tackle problems quickly (i.e., working off the more vulnerable fractions of the inventory while providing feedback on aspects of feasibility, reliability, etc.) will probably be preferred over those that follow conventional approaches. Further, it should not be assumed that there only one management approach will (can) be selected. Unresolved questions may require that several options be carried forward, at least for a time. Thus, technologies that can accommodate a wider range of "final" management approaches/options may prove to be more useful.

Sincerely,

R. C. Mason, Director
Waste Management and Remedial Action Division

RCM:vhw

DEPARTMENT OF THE ARMY
U.S. ARMY PRODUCTION BASE MODERNIZATION ACTIVITY
PICATINNY ARSENAL, NEW JERSEY 07806-5000

January 6, 1995

REPLY TO ATTENTION OF

AMSMC-PBR

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, Maryland 20874

Dear Mr.Patton

The U.S. Army Materials Command, Alexandria, Virginia has requested the Army Heavy Metals Management Office to review and comment on the Department of Energy (DOE) 10 November 1994 Federal Register Notice and the Lawrence Livermore National Laboratory evaluation factors. The original request was addressed to General L. E. Salomon, 28 November 1994.

This office has been working with the DOE EM-50 (Mr. Carl Cooley) and their consultant corporation BDM for approximately 18 months, to develop other Depleted Uranium (DU) uses and products in support of reducing DOE's $DUF_6$ stockpile. It should be noted that this effort required many hours of coordination with DOE, their contractor BDM and the Oil Well Drilling Industry (all gratis). During this period the army was never contacted or informed that DOE and their National Laboratory were preparing a notice for the Federal Register requesting separate or new proposals for other uses of DU. This office has already presented three proposals to DOE, which would reduce the $UF_6$ stockpile and benefit the U.S. Oil Well Drilling Industry. The proposals would also benefit the Kinetic Energy Penetrator Production Base providing significant work to retain that base. The Army's proposals are as follows:

- DU Drill Collars

- DU Well Penetrator

- DU Well Shape Charge Perforator

To date, this organization has received no response to our proposals.

Our greatest concern on the evaluation factors is that, the DOE should consider the overriding issue of the government's liability for the use of the $DUF_6$. Since it is government furnished material (GFM), does the government retain liability for the life cycle of any and all of it's uses. If so, this should be considered during evaluation of concepts/proposals.

Also the notice never identified the various levels of radioactivity of the $DUF_6$ stockpile. Two levels of radioactivity are represented. One represents the DU specification the Army uses <0.2% $U_{235}$ per 5 pounds of depleted $DUF_6$. The other however is considerably higher. The evaluation needs to consider which material is being used and the factors applied accordingly. A majority of the quantity of DOE,s stockpile is above that lower radiation level limit.

Point of contact at this office is Mr. George P. O'Brien Commercial (201) 724-3049, FAX (201) 724-4407

Thomas G. McWilliams

Thomas McWilliams
Chief, Life Cycle Readiness Division

Copy Furnished:
Headquarters, U.S. Army Materiel Command, Attention: SARD-ZC, 5001 Eisenhower Avenue, Alexandria, Virginia 22333-0001

STATE OF TENNESSEE
DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DOE OVERSIGHT DIVISION
761 EMORY VALLEY ROAD
OAK RIDGE, TENNESSEE 37830-7072

January 6, 1995

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd, 2nd Floor
Germantown MD 20874

Dear Mr. Patton

**STRATEGIES FOR THE LONG-TERM MANAGEMENT OR USE OF DEPLETED URANIUM HEXAFLUORIDE**

I appreciate the opportunity to comment on the U. S. Department of Energy's alternative strategies for the long-term management or use of depleted uranium hexafluoride and the evaluation factors that are being developed as guidelines for the reviewers conducting the assessment. The Tennessee Division of DOE Oversight is presently preparing to comment as instructed in the Federal Register. The comments will be mailed to Charles E. Bradley Jr., Office of Uranium Programs. A copy of the comments will be provided to you.

Please contact me if I can be of any future assistance. My telephone number and fax number are 615-481-0995 and 615-482-1835 respectively.

Sincerely

John Owsley

John Owsley, Assistant Director

PARSONS ENGINEERING SCIENCE, INC.

710 South Illinois Avenue • Suite F-103 • Oak Ridge, Tennessee 37830 • (615) 481-3920 • Fax: (615) 482-9841

6 January, 1995

Mr. Scott E. Patton
FESSP Washington Operation
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

Subject: EVALUATION FACTORS FOR DEPLETED URANIUM HEXAFLUORIDE ALTERNATIVES

Dear Mr. Patton:

I understand that your office is assisting the Department of Energy to identify uses or technologies that could be considered in selecting long-term management strategies for depleted uranium hexafluoride. In that capacity, your office recently developed a draft of evaluation factors for independent technical reviewers to use in assessing these technologies. In your letter, dated November 28, 1994 to J. Wyatt, you asked for our assistance in reviewing and commenting these evaluation factors.

I am happy to assist you in this effort. I distributed the evaluation factors to several key individuals within Parsons for their comments. Attached for your use please find a copy of our consolidated comments. For your convenience, I am also enclosing a copy of the evaluation factors you sent to us.

If you have any questions or require further assistance, please call me at (704) 558-4030 or Cynthia Farnsworth at (615)481-3920.

Very truly yours,

PARSONS ENGINEERING SCIENCE, INC.

Cynthia A. Farnsworth

for Stephen Marchetti

Vice President, Eastern Operations

SM/caf

PARSONS

Mr. S.E. Patton
6 January, 1995

Comments on Draft Evaluation Factors

Depleted Uranium Hexafluoride

I. General Comments

The five evaluation factors appear to be complete and would produce the desired results if the reviewer was extremely knowledgeable in this area. The evaluation criteria appear to require a detailed response to the Federal Register notice. If the response is only concepts, technologies, and thoughts, then the evaluation criteria is too comprehensive to be meaningful. Detail designs may not be available at this early evaluation stage to do proper justice to some of the criteria such as D&D costs.

II. Specific Evaluation Factor Comments

A. Environmental Safety and Health

For the most part these issues and concerns apply uniformly to all alternative concepts, including the base case of continued storage and surveillance.

The assumption should be made that all concepts can be made safe, including meeting existing regulations and guidelines for emissions provided the facilities cost are adequate.

Issues that effect siting would also be common to most alternative concepts.

Design specifications/configurations probably will not be available at the time the concept is submitted.

Two additional factors to be considered in the evaluation would be the degree of worker/public exposure to the depleted uranium hexafluoride and by product materials and the requirement for long term monitoring and reporting through alternative implementation.

B. Waste Management

Storage volumes should be a major consideration and does not appear to be addressed. Credit should be allowed for recommendations that would use the uranium or the fluorine in commercial usage.

The criteria for treating and handling depleted uranium hexafluoride and its byproducts should be stated-up front. The reviewer could then decide on each recommendation if the overall waste management factors were explicitly issues or non-issues.

If the concept has sufficient support and back-up documentation, the potential for waste minimization in manufacturing can be addressed.

The question of recycling depends on a number of factors. If the uranium is used as an armament, does recycling enter in with respect to salvaged equipment or is the use of uranium in the armament considered recycling?

Other considerations should be given to the potential to downgrade waste classifications through application of the alternatives.

C. Costs

If cost data is provided with the recommendation or concept, it can be evaluated in accordance with the evaluation criteria. Of the five items listed the first four can only be resolved by completing a feasibility study.

The cost avoidance issue by the sale of a byproduct can be addressed as part of the Waste Management issue. If some of the fluorine can be marketed as either HF or CaF2, this will impact on the plant costs and the processing requirements. It will also go a long way toward reducing the storage volume of the remaining waste products. Any concept that has marketable products or by products should be given a plus for the criteria evaluation factor.

Other considerations should include permitting costs, opportunity for government and private sector cost sharing, cost opportunities for reutilizing existing facilities and assets.

D. Technical Maturity

This evaluation factor should be first or second and is probably the easiest to evaluate. The four subfactors should be reordered to:

1. Bench or small scale

2. Developed or untested on a large scale

3. Design Conceptual or detail

4. Standard Industrial practice

Considerations should also include: reliability and maintainability history of alternative and the simplicity of the design.

At this early stage in concept evaluation the four classifications could be: (1)R&D, (2)Emerging, (3)Demonstration, and (4)Mature.

If the technology or concept is R&D, the time to achieve availability and the probability of success not only depend on the technology, but would be dependent on the annual level of funding.

E. Socioeconomic Issues

Item 1 should consider specifically the availability of a competent workforce and the economic impact and availability of adequate training.

Items 2 and 3 probably have a bearing on plant siting.

It is also suggested that the level of anticipated regional regulatory acceptance should be a factor in this category.

At this time, one can only guess at the level of detail provided to the reviewers. It is also assumed that the reviewer is a knowledgeable person. One would expect three to five pages describing the concept or recommendation. The technologies could be evaluated using the following criteria:

A. What is the status of the technology (now factor D)

B. Are there marketable products (other that armament and shielding)?

C. Will the resulting waste/product streams reduce the overall storage volume? Will the change in waste form reduce storage costs?

D. Is there something unusual about the concept that would effect plant siting?

E. Is there any cost data available, or a schedule for implementation?

F. What are the potential ES&H issues? Will there be a potential socioeconomic impact?

Battelle
. . . Putting Technology To Work

505 King Avenue
Columbus, Ohio 43201-2693
Telephone (614) 424-6424
Facsimile (614) 424-5263

January 6, 1995

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Boulevard - 2nd Floor
Germantown, Maryland 20874

Dear Mr. Patton:

In response to your request for review and comment on the draft Evaluation Factors for the Depleted Uranium Hexafluoride Management Program, we offer the following comments:

1. We believe that the list of Draft is comprehensive and addresses all of the significant issues.

2. It was noted that neither the *Federal Register* notices nor the Draft Evaluation Factor Document identify the drivers for DOE's initiative (i.e., why is this program being proposed?). A clear definition of the technical needs will make the evaluation process significantly more effective.

3. The Review Instruction sheet states that each response on the alternative strategy be evaluated on its own merits and not in comparison to other alternatives or recommendations. However, several of the factors need to be evaluated on relative terms in order to be meaningful. For example, the environmental, safety, and health (ES&H) issues associated with the proposed alternative are best evaluated in terms of reduced or increased risks relative to the existing conditions (i.e., Assuming "No Action"). Similarly the cost of the proposed alternative should be evaluated from the standpoint of benefits relative to "No Action".

4) It is recommended that prior to the start of the evaluation process a "checklist" of key items be developed to assist the reviewers. This will help in maintaining consistency among different reviewers and review teams.

We appreciate this opportunity to participate in the development of the evaluation factors. We are greatly interested in continued involvement in this process and look forward to being part of the independent evaluation teams.

If you have any questions or if you need any additional information, please feel free to contact V. Pasupathi of my staff at 615-220-4019 or me at 615-220-4036.

Sincerely,

B. Michael Eisenhower, Ph.D.
Director, Oak Ridge Operations

COGEMA, INC.

FRANK A. SHALLO
VICE PRESIDENT, MARKET DEVELOPMENT

January 6, 1995

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd. 2nd Floor
Germantown, MD 20874

Dear Mr. Patton:

Your letter of November 28, 1994 solicits comments to a set of draft evaluation factors for independent technical review of proposed uses or management technologies for depleted uranium hexafluoride ($dUF_6$) resulting from U.S. enrichment activities.

While we have no additional evaluation factors to offer, we would like to take this opportunity to encourage the U.S. Department of Energy and its contractors to move forward with a program for (i) construction and operation of $dUF_6$ conversion facilities for safe, long-term storage in the $U_3O_8$ form, pending future decisions concerning reuse or disposal, and (ii) recycle of hydrofluoric acid (HF) into the North American commercial market.

In our view, long-term retrievable storage of uranium tails in the $UF_6$ form is inappropriate due to the volatility of $UF_6$ when exposed to air. The HF and uranyl fluoride ($UO_2F_2$) produced therefrom are two hazardous waste products which pose significant health hazards.

Conversion to $U_3O_8$ is, in our opinion, the logical solution and we remain ready to participate with other U.S. companies in implementing the conversion of $dUF_6$ to $U_3O_8$. Enclosed is a copy of our recent submission to Mr. Charles Bradley, Jr., in response to a recent Federal Register notice which provides information that may be helpful to you.

Thank you for the opportunity to offer comments for the DOE's consideration.

Sincerely,

Frank A. Shallo

Frank A. Shallo

FAS/ej

7401 WISCONSIN AVENUE, BETHESDA, MARYLAND 20814-3416 TEL. (301) 986-8585 TELEX 892605 TELEFAX: (301) 652-5690

WILLIAM J. WILCOX, JR.
MANAGEMENT CONSULTANT

412 NEW YORK AVENUE
OAK RIDGE, TN 37830
(615) 483-4990

1/8/95

Mr. Scott E. Patton

Re: Evaluation Factors

1. You might want to consider another factor, and that is the potential VALUE or return to the US Treasury, or to DOE, or to the US Economy or whatever? Your factor C covers costs - but what of the benefits?

2. All the factors seem to assume the uses proposed are near-term. You might wish to consider broadening D. to include a category which allows for evaluation of some far-out, future possibilities which are of potentially much more value to the Nation than any of those we see in the Fed. Register. The category might be Exploratory or Potential Long Range?

Wm Wilcox Jr

Parsons Brinckerhoff
1660 Lincoln Street
Suite 2000
Denver, CO 80264-2(
303-832-9097
Fax: 303-832-9095

January 9, 1995

Scott E. Patten
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

CONTRACT: DE-AC34-93RF00072
IDENTIFICATION: PB/RF-CCN-0-94-0288
**SUBJECT:** Uranium Hexafluoride EIS

Dear Mr. Patten,

Parsons Brinckerhoff, contractor for the Rocky Flats Site-Wide EIS, was requested to provide comments on the "Evaluation Factors for Independent Technical Reviewers" for the Uranium Hexafluoride EIS.

The following are specific comments on the part II evaluation factors:

A. Add item "4. Changes in the susceptibility to accidents or operational releases due to volatility of the materials, form, or processing operation, including the need for special facility containment or control systems."

E. Consider moving item "2. Public acceptance" to section "F. Other factors". For the purposes of the "Evaluation Factors for Independent Technical Reviewers", define "public". For example, depending on the purpose and need for the Uranium Hexafluoride EIS, "public" could be defined as follows: anyone with an interest in the outcome of the Uranium Hexafluoride EIS, including employees, the general public, regulators, elected officials, government agencies and others. Workers, DOE and regulators could be defined as internal publics, and those not directly associated with site operations could be defined as external publics.

Item "1. Employment" needs to evaluate the direct employment associated with the addition of the facility to handling the $UF_6$, but also indirect or off-site employment included in the support industries or vendors supplying goods and materials to the processing facility.

One other consideration in Socioeconomics is the potential replacement of other processing or mining plants and facilities associated with a new product stream from the reprocessing of the $UF_6$.

For further questions or clarification on technical comments, please contact Lyman Parkhurst at 303-832-9091. For questions or clarification on public involvement comments, contact Cathy Coghill at 303-832-9091.

Sincerely,

PARSONS, BRINCKERHOFF QUADE & DOUGLAS, INC.

David B. Winsor
Project Manager

DBW:CC:sg

# PURDUE UNIVERSITY

SCHOOL OF NUCLEAR ENGINEERING

January 9, 1995

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd. 2nd Floor
Germantown, MC 20874

Dear Mr. Patton:

In response to your request for comments on the evaluation factors to be used by reviewers for proposals relative to Management of Depleted Uranium Hexaflouride, I have only one comment. The U238 is potentially useful for producing plutonium fuel in breeder reactors and thus will one day become a valuable resource. In this regard, I suggest that the ability to recover the U238 in the future be an evaluation factor.

Sincerely,

Victor H. Ransom
Professor and Head

VHR/jh

95.3

OAK RIDGE NATIONAL LABORATORY
MANAGED BY MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE U. S. DEPARTMENT OF ENERGY

POST OFFICE BOX 2008
OAK RIDGE, TENNESSEE 37831-6256

January 9, 1995

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, Maryland 20874

Dear Mr. Patton:

**Comments on Evaluation Factors Concerning Management of Depleted Uranium Hexafluoride**

Reference: Letter, S. E. Patton to A. W. Trivelpiece, "Requesting Comments on Draft Evaluation Factors Concerning Depleted Uranium Hexafluoride Disposition Options," November 28, 1994

We appreciate the opportunity to review the draft evaluation factors contained in the reference correspondence. The enclosure accompanying this letter summarizes our comments. If you have any questions on these comments, please call Allen Croff at (615) 574-7192.

Sincerely,

James O. Stiegler

Alvin W. Trivelpiece - RC
Director

AWT:jdb

Enclosure

cc: A. G. Croff
R. O. Hultgren, DOE/ORO
L. E. McNeese
G. E. Michaels
J. O. Stiegler

# COMMENT ON EVALUATION FACTORS CONCERNING MANAGEMENT OF DEPLETED URANIUM HEXAFLUORIDE

## General Comments

- An introduction to the evaluation comments should clearly state that the factors are to be applied to each step of the entire system required to implement a proposed technology, not just the step implementing the technology per se. If the proposer does not specify a cradle-to-grave system, the evaluators or their technical support staff should make a "best effort" attempt to supply this information before the evaluation commences.

- It is necessary to specify common assumptions to achieve a meaningful result, especially if the evaluators will not be centralized for the evaluation process. For example, specific economic assumptions, measures of environmental impacts (e.g., population or individual doses), parameters of potential disposal sites.

## Specific Comments

*ES&H:* The statement of all items implies that a list of issues, configurations, specifications, etc. will be the basis for the evaluation. This factor is capable of quantification and this should be done. Specifically, the evaluation factor should consider routine and accidental impacts on workers and the public from releases of radioactive and chemical effluents as well as "physical" accidents (collisions, industrial mishaps).

*ES&H:* Although it should be clear from the statement of the Waste Management factor, this item should clearly state that the ES&H factor is related to contemporary risks from operating facilities.

*ES&H:* An additional item should be added that addresses the environmental impacts of constructing and operating the various facilities for each alternative.

*Waste Management:* This factor can be restructured to better clarify the attributes of various options. Specifically, the sub-factors should be as follows:

- The characteristics and volume of the depleted uranium waste form and the environmental impacts of disposing of it.

- The characteristics and volume of each secondary waste (including D&D) stream and the environmental impacts of disposing of each.

- The potential for waste minimization in the above and any environmental impacts of same.

*Waste Management:* In the case of depleted uranium, any beneficial use of the material (i.e., recycling) except use as a fuel in nuclear reactors (which destroys it) is only a form of interim storage. No matter whether the use is uranium bullets, counter-weights in aircraft, or shielding, the uranium will eventually be declared a waste and sent for disposal (or, in the case of munitions, eventually require expensive remediation). Thus, the sub-factor concerning recycling should be deleted from this factor since management as a waste will be required in any case.

*Costs:* A sub-factor should be included to acknowledge the net cost or savings from recycling depleted uranium (this may be included in sub-factor 4, although it is not clear).

*Costs:* Although implied in the introduction, development (RD&D) costs should be included as an explicit sub-factor.

*Costs:* The decision made concerning the disposition of the existing $UF_6$ is likely to set a precedent concerning disposition of future enrichment plant tails, which are almost exclusively the result of uranium enrichment for civilian purposes. The estimated cost of such disposition would add substantially to the cost of uranium for existing once-through nuclear reactors, with significant implications for the competitiveness of these reactors with other energy sources and with nuclear fuel cycles involving reprocessing and recycle. The broader implications and societal costs of the alternatives being considered in this evaluation need to be considered, and this consideration should be an explicit sub-factor under this item.

*Costs:* Our understanding is that the fluorine contained in the enrichment plant tails represents a substantial fraction of the annual domestic production of fluorine. The economic implications of bringing this large amount of material onto the market in a relatively short time needs to be considered.

STATE OF TENNESSEE
DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DOE OVERSIGHT DIVISION
761 EMORY VALLEY ROAD
OAK RIDGE, TENNESSEE 37830-7072

January 9, 1995

Charles E. Bradley, Jr.
Office of Uranium Programs
Office of Nuclear Energy
US Department of Energy
19901 Germantown Road
Germantown MD 20874

Dear Mr. Bradley

**ALTERNATIVE STRATEGIES FOR THE LONG-TERM MANAGEMENT OF DEPLETED URANIUM HEXAFLUORIDE RESOURCES AT SEVERAL GEOGRAPHIC LOCATIONS ADVANCE NOTICE OF INTENT TO PREPARE AN ENVIRONMENTAL IMPACT STATEMENT**

In accordance with "Federal Register / Vol. 59, No. 217 / Thursday, November 10, 1994 / Notices, pages 56325 through 56327" the Department of Energy (DOE) is requesting public comments on the scope of the above advance notice of intent (ANOI) to prepare an environmental impact statement (EIS). In response to that request, the Tennessee Department of Environment and Conservation, DOE Oversight Division, requests the following items be evaluated in the EIS:

- Incorporate and evaluate appropriate information from the currently unpublished document entitled "Project Management Plan for the $UF_6$ Cylinders Project for the Oak Ridge K-25 Facilities". Actions being proposed or considered for the K-25 Site must be addressed in the EIS in accordance with the National Environmental Policy Act (NEPA) process prior to the modifications or major projects being initiated. Particularly, the range of alternatives noted in the Federal Register should be expanded to include the alternatives and associated details listed in the above K-25 Project Management Plan.

- Construction of new cylinder storage pads as well as the advantages and disadvantages of having $UF_6$ stored at the particular sites where the new pads will be located should be evaluated. A new pad is planned for construction at the K-25 Site which must be addressed in the EIS in accordance with the NEPA process prior to initiation of construction.

- The costs for each alternative should be evaluated in as much detail as practical.

- It is noted that a plan to convert $UF_6$ to an oxide for the purposes of stable long-term storage will be evaluated in the EIS. Construction of a cylinder refurbishment facility should also be evaluated. Construction of conversion and refurbishment facilities should be evaluated for appropriate locations with the intent of choosing only one site for both facilities.

- Gradual conversion of $UF_6$ to an oxide over a 15 - 20 year time-frame should be considered in order to mitigate short term costs for conversion. Converting deteriorated cylinders first would allow the use of smaller refurbishment facilities and reduce the required number of new pads.

- The production and treatment of all waste byproducts resulting from any action or inaction should be addressed for each alternative.

In addition to the above comments on the Federal Register, we have reviewed the evaluation factors distributed by Mr. Scott E. Patton in November, 1994 and recommend that regulatory requirements be included in the evaluation factors.

I appreciate the opportunity to provide input into the depleted $UF_6$ NEPA process and your consideration for incorporation of the above requests into the EIS.

Sincerely

John Owsley for

Earl C. Leming
Director

cc Ben L. Smith
Michael H. Mobley
Thomas S. Tison, DOE/K-25
Scott E. Patton, Lawrence Livermore National Laboratory
Charles Brown

wm0803.04

MARTIN MARIETTA ENERGY GROUP

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CLYDE C. HOPKINS
PRESIDENT

January 10, 1995

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Boulevard, 2nd Floor
Germantown, Maryland 20874

Dear Mr. Patton:

I have been asked by Mr. A. T. Young, President and Chief Operating Officer of Martin Marietta Corporation, to review your draft of the evaluation factors to be used by independent technical reviewers in evaluating the proposed uses of management technologies for depleted hexafluoride ($DUF_6$). As you know, Martin Marietta Energy Systems, Inc., is managing the $DUF_6$ inventory for the U.S. Department of Energy, and any management improvements or future uses are of interest to us.

Based on the knowledge and experience of our staff who have been involved in managing the $DUF_6$ inventory, the criteria that you described in your letter to Mr. Young appear to be reasonable and to include the factors we consider important. We would, however, suggest one addition to the "cost" evaluation factor. The $DUF_6$ inventory is currently stored in a variety of containers, some of which have incurred accelerated corrosion. These containers, while adequate for continued storage, may not meet the established criteria for transportation over public roads and/or the criteria for being emptied by use of an autoclave. Depending upon the technology or use being proposed, the cost of transporting and emptying these different types of containers may be significant. It would therefore seem appropriate to perform some cost modeling for the various proposed technologies for inclusion in your evaluation criteria.

We hope that our input is useful to you. Again, thank you for the opportunity to review your draft.

Sincerely,

Clyde Hopkins

Con Edison

Consolidated Edison Company of New York, Inc.
Indian Point Station
Broadway & Bleakley Avenue
Buchanan, New York 10511-1099

January 10, 1995

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

Dear Mr. Patton:

I am responding to your letter of November 28, 1994 to Mr. Eugene R. McGrath, Chairman and Chief Executive Officer of Consolidated Edison, in which you requested comments on your draft document, "Evaluation Factors for the Depleted Uranium Hexafluoride Management Program."

At this time, Consolidated Edison does not wish to submit any comments, since we would not utilize such a program at Indian Point 2.

Sincerely,

Victor E. Mullin
Manager,
System Engineering & Analysis

VEM/jk
cc: S. E. Quinn

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
Upton, Long Island, New York 11973

(516) 282-4492
FTS 666-

Office of the Director

December 22, 1994

Dr. Carson L. Nealy
Area Manager
U.S. Department of Energy
Brookhaven Area Office
Bldg. 464
Upton, NY 11973

Dear Dr. Nealy:

Subject: Comments on Evaluation Factors for Assessing Proposed Uses or Management Technologies for Depleted Uranium Hexafluoride

Reference: Letter, Scott E. Patton to Nicholas P. Samios, no title, dated November 28, 1994. Management of Depleted Uranium Hexafluoride Request for Recommendations (**Federal Register**, Vol. 59, No. 217, November 10, 1994, pg. 56324). Alternative Strategies for the Long Term Management of Depleted Uranium Hexafluoride Resources at Several Geographical Locations (**Federal Register**, Vol. 59, No. 217, November 10, 1994, pg. 56325).

Based on a review of the proposed evaluation factors and the above referenced **Federal Register** notices, the two concepts below should be added to the evaluation list as stand alone factors to be certain they are not overlooked.

Concept 1: Regardless of the facility which is ultimately chosen to manage the $UF_6$ (DOE or NRC/state licensed), the facility must have in place an approved material control and accountability system for the uranium in whatever form it finally remains in or is converted to. As a subtopic, the time required to amend an existing radioactive material license or apply for a new license (NRC or Agreement State) must be considered, especially for new facilities, since this time may exceed two years.

Concept 2: $UF_6$ and its technology is listed in the newly released, Interim Guidelines on Export Control and Nonproliferation, November 3, 1994 as having export

controls (ref. NSG Section 7.0 of INFCIRC 254/Rev. 1/Part 1/Mod 2 and Sections 2.6, 3.1, and 3.7 of INFCIRC 254/Rev. 1 Part 2 - NTRB Section 3.1). The facility or facilities selected or constructed for the management of the $UF_6$ and its technology must have in place an approved system to ensure that export controls are not bypassed or violated.

If you have any questions or require further information, please contact K. Dahms at (516) 282-4051.

Sincerely,

M. S. Davis
Associate Director

c: Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

R. Reaver, BNL
K. Dahms, BNL

PAI

PAI CORPORATION

116 Milan Way
Oak Ridge, Tennessee 37830

Telephone (615) 483-0666 • Fax: (615) 481-0003

January 12, 1995

Mr. Scott E. Patton
Fission Energy And Systems Safety Program
Lawrence Livermore National Laboratory
Washington Operations
20201 Century Boulevard, Second Floor
Germantown, Maryland 20874

SUBJECT: Alternative Strategies for Long-Term Management of $UF_6$
Comments by Mr. August Legeay

REFERENCE: Letter to A. Legeay from S. Patton dated November 28, 1994

Dear Mr. Patton:

In accordance with your request in the above referenced letter, attached please find comments provided by Mr. Gus Legeay on the subject program. Mr. Legeay is currently on the staff at PAI, and he is currently involved in various tasks in support of DOE at the Oak Ridge K-25 Site. These comments are provided by Mr. Legeay independently of any of the tasks in which he is engaged, thus they are provided on the basis of his ongoing interest in the program and of his willingness to be of assistance in this matter. Also attached is a brief summary of Mr. Legeay's experience.

If you need additional information or if you have any questions, please do not hesitate to contact Mr. Legeay or me at 615-483-0666.

Yours truly,

JGhoon

Jeff Goodman
Program Manager

JG:kd/8T--FESSP.LET

Attachments

**Comments on the Depleted Uranium Hexaflouride Management Program**
**by Gus Legeay—January 12, 1995**

## I. Evaluation Factor A.1—Issues that may arise as a result of operations, handling, storage, and disposal, including effluents and emissions

About any strategy for long-term management of depleted $UF_6$ would result in the handling and movement of nearly 50,000 cylinders of $UF_6$, which would require a careful and thorough assessment of the condition of these cylinders. There has been an ongoing program of inspections of these cylinders and their storage yards; high-volume air monitoring for uranium and air sampling for HF; investigation of the yards, valves and plugs, and cylinder wall corrosion; cylinder manufacturing history, specifications, nameplate data, working pressure, volume determination and certification; and practice in cylinder evacuation (early use of oil-filled vacuum pumps without appropriate traps). Operating history such as cylinder net weights vs. weights based on manufacturers' certified volume, and findings from inspections and incidents over the years, are some examples of information and data obtainable from the Department of Energy. This information should be thoroughly reviewed.

Some cylinders, as would be expected from a review of cylinder conditions, will require that the temperature and pressure of vaporization be lowered to such levels that the rate of feed to the process is significantly reduced. A special transfer system may be required. (By way of insight, such a problem can readily be handled in an operating gaseous diffusion plant where the cylinder can be valved to a matching assay point and fed at ambient temperature.)

There are some differences among the vehicles used for the in-plant loading transport and unloading of $UF_6$ cylinders at the three gaseous diffusion plants. Differences exist in the facilities served by these cylinder transport vehicles. Design differences should be examined, operating safety and performance records, accidents, and abnormal incidents should be compared. A particular point to be made is that there has been a good tried-and-proven record built up with this fleet worth considering (the "wheel" does not need to be reinvented with the associated anguish of an extended shakedown of a completely new design). You will not have 50 years to do it.

## II. Evaluation Factor A.2—Issues that may restrict site choices when constructing or operating a facility that employs this technology or application

Results obtained through an investigation of the condition of cylinders, as discussed in an earlier paragraph, will provide criteria for establishing the limits on the distances a cylinder can be moved. It is expected that these limits would require that most any strategy selected for the long-term management of depleted $UF_6$ be done on each diffusion plant site near the depleted $UF_6$ cylinder storage yard(s).

## III. With some uncertainty as to where this fits (if it does) in the evaluation factors, I also submit the following

Of highest importance to safe and efficient operation (following recruitment of qualified personnel) is the quality of procedures and the quality of training. Safe operation is not a staff function; it is the line organization's responsibility to write the procedures and do the training. The staff may only supply support services. This should be a team effort, with participation at all personnel levels and with particular emphasis on the involvement of the hands-on, hourly worker.

Emphasis should be given to providing technical and line management, and the hands-on worker, with an in-depth knowledge of the physical, chemical, radioactivity, and toxicity characteristics of the $UF_6$ material that will be in their work environment, but expected to be in a safe, contained condition. It is recognized that this is only an introduction to a major task of writing the procedures and carrying out the training programs necessary for a strategy to manage depleted $UF_6$, such as a process to reduce $UF_6$ to a chemically inert compound.

ST–FESSP.LET

Gus Legeay
Signature

**Brief Resume**
**for**
**August (Gus) J. Legeay**

PAI Corporation
116 Milan Way
Oak Ridge, Tennessee 37330
Phone: (615) 483-0666
Fax: (615) 481-0003

My experience covers more than 20 years of increasing responsibility in gaseous diffusion plant process engineering at the Paducah Plant, and 12 years as Operations (Production) Division Manager of the Oak Ridge Gaseous Diffusion Plant, operated by Union Carbide Nuclear Division for the Department of Energy. A special assignment was chairing the Three-Plant Safety in $UF_6$ Handling Committee, made up of representatives from the Oak Ridge, Paducah, and Portsmouth Gaseous Diffusion Plants, from 1973 until my retirement in 1984. This committee was established at the request of DOE to improve industrial safety aspects of handling $UF_6$ and to reduce the risk of personnel exposure and environmental insults from the release of corrosive gases.

From 1986 to 1989, I was with Midwest Technical, Inc. (a division of CDI Corp.), Oak Ridge, Tennessee, as a part-time consultant; the majority of my work was involved with the historical investigation of hazardous wastes sites at the K-25 Site. Six months were spent in an operations review of the K-1435 TSCA Incinerator Facility; two weeks were spent later as a member of a committee established by DOE to investigate $UF_6$ releases at the Paducah and Portsmouth Plants.

In 1989, I joined PAI Corporation in Oak Ridge, Tennessee, where I continued to perform historical investigations of hazardous waste sites at the K-25 Site. A few months were spent as the K-25 representative on waste volume estimates of 140 solid waste management units located at the Paducah Plant. During September 1993, I also served on an oversight committee looking into operating problems in the Portsmouth Gaseous Diffusion Plant.

My work is currently scheduled on 2½ days per week (1040 hr/year); this is a full-time schedule for me.

Linda Malinowski
615/483-0666

**NO COMMENTS**

Defense Nuclear Agency
6801 Telegraph Road
Alexandria, Virginia 22310-3398

JAN 23 1995

Mr. Scott E. Patterson
FESSP Washington Operations
Lawrence Livermore National Laboratories
20201 Century Blvd., 2nd Floor
Germantown, MD 20874

Dear Mr. Patterson:

We have reviewed the request for comments on the evaluation factors for the depleted uranium hexaflouride management program, together with the Federal Register announcements and the proposed evaluation factors. The proposed factors cover most of the areas of interest as specified in the Federal Register announcements. We suggest two additional factors (attached) be included. These are necessary to fully cover all the areas of interest specified in the announcements.

Sincerely,

GEORGE W. ULLRICH
Deputy Director

Attachments
Additional Evaluation Factors

## Additional Evaluation Factors for Depleted UF6 Management Program

**G. Government Involvement.** Evaluate the amount of active government involvement or participation necessary for the successful development of a product or implementation of a management technology in terms of

1. Government Funding.

2. Government Oversight.

3. Regulatory Actions.

**H. Schedule.** Evaluate the proposed schedule for the successful development of a product or implementation of a management technology in terms of

1. Estimated time to initial production/implementation.

2. Consumption rate for UF6/Period required to deplete current UF6 stockpile.

WILLIAM R. MARTIN
ASSOCIATE DEAN

THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING

2401 EECS BUILDING
1301 BEAL AVENUE
ANN ARBOR, MICHIGAN 48109-2116
313 763-5464 FAX 313 763-9487
wrm@umich.edu

January 25, 1995

Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd. 2nd Floor
Germantown, Md 20874

Dear Mr. Patton:

Thank you for the opportunity to comment on your draft, *Evaluation Factors for Depleted Uranium Hexafluoride Management Program,* dated November 1994. I realize that you had asked for my comments before now, but I have been busy with a new position and did not have an opportunity to review it until now.

I have taken a look at what you have proposed and have only one comment. Perhaps you might consider having as one of the factors whether or not there may be advantages to be gained from using a technology (or developing a technology) that could be used for other waste disposal problems associated with the nuclear industry. That is, if significant investments are to be made in a particular technology, it would be desirable to be able to show other applications of that technology as opposed to a technology dedicated to solving a particular problem ("multiple use" vs. "single use"). Other than that, I have very little to add to your document.

Thanks again for including me as one of your reviewers and I hope this letter is useful to you.

Sincerely yours,

William R. Martin
Professor of Nuclear Engineering

**Department of Energy**

Oak Ridge Operations
P.O. Box 2001
Oak Ridge, Tennessee 37831—

February 10, 1995

Mr. Scott E. Patton
FESSP Washington Operations
Lawrence Livermore National Laboratory
20201 Century Blvd., 2nd Floor
Germantown, Maryland 20874

Dear Mr. Patton:

**ENVIRONMENTAL RESTORATION COMMENTS ON EVALUATION FACTORS FOR INDEPENDENT TECHNICAL REVIEWERS: DEPLETED URANIUM HEXAFLUORIDE MANAGEMENT PROGRAM**

The Environmental Restoration Division (ERD) at Oak Ridge has completed its review of proposed evaluation criteria to be used by technical reviewers in evaluating proposed uses and management technologies for DOE's inventory of depleted uranium hexafluoride.

ERD has no comments on the list of proposed evaluation criteria provided us for review, however we offer the following comments for your consideration. First, considering State views on perceived equity issues, locating any processing facilities should be carefully evaluated. Second, management systems and proposed technologies should be evaluated in the context of a system that is easily translated to an innovative contracting approach.

If you have any questions on these comments or would like to discuss them further, please contact Bill Cahill at (615) 241-4830.

Sincerely,

Robert C. Sleeman, Director
Environmental Restoration Division

# POWER VENTURE ASSOCIATES

## MARY WOLTER GLASS

Ms. Glass is a trained environmental consultant with wide-ranging background in all aspects of the field including impact assessment, monitoring, permitting and reporting. With over fourteen years of experience, Ms. Glass has special expertise in the area of environmental impacts associated with the construction and operation of projects for residential, commercial, industrial and utility clients.

### EXPERIENCE

As a principal investigator for Dames and Moore, an international environmental consulting firm, Ms. Glass performed many environmental impact studies. She was responsible for complete environmental assessments of land, air, water, socioeconomic and other factors for commercial and residential properties. With special expertise in siting, land resources and socioeconomics, Ms. Glass contributed to numerous environmental impacts studies at diverse sites around the country for industrial, government or utility clients.

As a project manager for Fred C. Hart Associates, Ms. Glass directed a variety of environmental studies for corporate and government clients. Major studies included an analysis of the environmental effects of a new technology and an assessment of its cumulative impacts in commercial use. Ms. Glass also conducted a survey of state regulatory activities related to hazardous wastes.

As a principal in an energy development company, Ms. Glass managed all aspects of the environmental permitting and monitoring process for a number of projects. Ms. Glass directed the efforts of a team of engineers in site investigations, developing special studies required for permitting, preparing permit documents and negotiating with state officials to assure permit approval. Ms. Glass developed and provided oversight for ongoing compliance and monitoring activities required.

Ms. Glass has also served in government positions at the state and federal level which involved the assessment of environmental impacts, development of mitigation options and the review of environmental effects of program activities.

### EDUCATION

Ms. Glass received a B.A. from the University of Michigan, an M.A. in Environmental Management from the University of California at Los Angeles, and an M.B.A. in Finance from George Washington University (Beta Sigma Gamma). She is an Officer and Director of the Women's Council on Energy and the Environment,.Washington, D.C.

3900 NORTH FAIRFAX DRIVE ♦ SUITE 403 ♦ ARLINGTON, VIRGINIA 22203 ♦ (703) 522-0940

# Brian K. Hajek

## Narrative Resume

Mr. Hajek began his nuclear engineering career in 1966. He has worked in industry, government, and education during this time, and has been active in professional activities as a member of the American Nuclear Society, Health Physics Society, and Sigma Xi.

He started his career at the Battelle Research Reactor in Columbus, Ohio, where he was SRO licensed and responsible for examining irradiated naval reactor fuel using neutron radiography. He developed designs for several irradiation facilities, and supervised their construction and use for numerous irradiation experiments.

He began working as a graduate student at The Ohio State University in 1968, where he was SRO licensed on The Ohio State University Research Reactor (OSURR) until 1986. In 1971, he returned to full time work becoming the Reactor Supervisor, responsible for the maintenance program, operator training programs, the research programs of the facility, and all liaisons with the NRC. In 1974, Mr. Hajek was named the Associate Director of the Nuclear Reactor Laboratory, and in 1980, he became Director of the Nuclear Services and Training Laboratory and an Adjunct Assistant Professor in the Nuclear Engineering Program. In 1986, Mr. Hajek was appointed a Research Scientist in the Nuclear Engineering Program and a member of the Graduate Faculty at The Ohio State University.

From 1978 to 1988, he was a consultant with the U.S. Nuclear Regulatory Commission. In this capacity, he was a Certified Operator Licensing Examiner on Boiling Water and Research Reactors. He gave license examinations at 27 BWRs during this period, making about 80 plant visits, and examining more than 300 candidates, and also performed training department performance audits at several facilities. In 1982 and 1983, he served as a consultant to Commissioner John Ahearne on matters related to implementing education requirements for licensed operators, and the regionalization of the Operator Licensing function.

In 1979, Mr. Hajek helped to found Nuclear Education and Training Services, Inc. NETS provides technical and training services to the nuclear industry. Its clients have included General Electric, Science Applications International Corporation, the Public Utility Commission of Ohio, the Electric Power Research Institute, and more than three dozen nuclear power plants. As President of NETS, Inc., Mr. Hajek is responsible for both marketing and project management. Recent projects have included system description development; General Employee Training audiovisual module production; exam bank development, updates, and revisions; and pre-license and requalification audit examinations for licensed operator training programs.

At The Ohio State University, Professor Hajek has taught courses in nuclear instrumentation, hydraulics and measurements, and a BWR systems course that includes ten weeks of on-campus coursework for graduate students in nuclear engineering, followed by one week of on-site simulator operation. He has done research in neutron radiography, neutron activation analysis, core flux mapping, gang-mode rod movements in BWRs, and artificial intelligence applications to power plant control room operations. He has managed several projects sponsored by the U.S. Department of Energy. One project used artificial intelligence techniques to provide operator aides to reactor operators. These efforts are aimed at providing enhanced capabilities to Safety

Parameter Display Systems in the areas of procedure management and causality identification. Perry is used as the reference plant. System testing is performed by running scenarios on the Perry simulator. Another project used artificial intelligence techniques to perform root cause analysis on a heavy water reactor using the Savannah River K Reactor as the reference plant. Professor Hajek is also a member of the Reactor Operations Committee for the OSURR, and a member of the College of Engineering Committee on Engineering Applications of Artificial Intelligence and Expert Systems.

Since 1992, Professor Hajek has been involved in the development of Fact Sheets and display exhibits for disseminating information on Low-Level Radioactive Waste to the general public, many presentations to news and civic organizations. This effort was sponsored by the Midwest Interstate Compact for Low-Level Radioactive Waste Disposal. He is currently managing a project that is a cooperative effort among Ohio State University, the University of Cincinnati, the U.S. Department of Energy, and Ohio industry to develop university courseware on power plant operating principles using the full-function plant simulators at three currently operational nuclear power plants.

Other activities have included serving as a consultant to Temple, Barker, Sloane, Inc., with responsibility for a management audit of the nuclear division of a small utility with two operational reactors and a third reactor under construction (1981); being a member of the INPO committee to establish guidelines for the Shift Technical Advisor position (1980); being a member of the Nuclear Power Advisory Committee for Terra Technical College, Fremont, Ohio (1979-1982); and being a member of the Ohio Governor's Citizens' Advisory Council which considered matters dealing with nuclear power safety in Ohio (1987-1989).

Mr. Hajek received his MS in Nuclear Engineering from The Ohio State University in 1972, and a BS in Physics and BA in Math from Otterbein College in 1966.

He is the author or coauthor of more than 60 papers, presentations, and technical reports.

**American Nuclear Society**: Member since 1971. Member Human Factors Division Executive Committee, 1993 - ; At-Large Member of Professional Divisions Committee, 1992 - ; Chair, Reactor Operations Division, 1991-1992; Vice Chair, Reactor Operations Division, 1990-1991; Secretary, Reactor Operations Division, 1989-1990. Member of Reactor Operations Division Executive Committee, 1986-1989. Member of Ad Hoc Committee for establishing the Education & Training Division, 1986-1987. Vice Chair of the Training Committee in the Technical Group on Human Factors. Member of the Technical Program Committee for the Fourth, Fifth, Sixth, Seventh, Eighth, Ninth, tenth, & Eleventh Symposia on the Training of Nuclear Facility Personnel, 1981, 1983, 1985, 1987, 1989, 1991, 1993, 1995. Member of the Program Committee for the Conference on Research, Test, & Training Reactors, 1974. Session Chairman or Co-Chair for each of the above conferences, and for the ROD Topical Meeting, 1981. Midwest Nuclear Training Association Annual Instructor Training Workshop, Co-Director 1986 - 1990, Director 1991 - present.

**DR. WALTER B. LOEWENSTEIN**

DR. WALTER B. LOEWENSTEIN IS A PROFESSIONAL CONSULTANT SPECIALIZING IN ENERGY AND NUCLEAR TECHNOLOGY.

DR. LOEWENSTEIN WAS DEPUTY DIRECTOR OF THE NUCLEAR POWER DIVISION AND DIRECTOR OF THE SAFETY TECHNOLOGY DEPARTMENT AT EPRI UNTIL 1989.

PRIOR TO JOINING EPRI IN 1973, DR. LOEWENSTEIN WAS THE DIRECTOR OF THE APPLIED PHYSICS DIVISION AT THE ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS. PREVIOUSLY, HE HAD SERVED IN VARIOUS RESEARCH AND TEACHING CAPACITIES AT OHIO STATE UNIVERSITY AND AT THE LOS ALAMOS SCIENTIFIC LABORATORY.

AUTHOR OF OVER 40 PUBLICATIONS AND HOLDER OF THREE NUCLEAR REACTOR PATENTS, DR. LOEWENSTEIN WAS ONE OF THE PARTICIPANTS IN THE "RISK ASSESSMENT REVIEW GROUP REPORT" TO THE U.S. NUCLEAR REGULATORY COMMISSION. HE AUTHORED VARIOUS PAPERS ON THE WATER REACTOR SAFETY PROGRAM AT EPRI FROM 1976 TO 1986.

DR. LOEWENSTEIN EARNED A B.S. DEGREE IN PHYSICS AND MATHEMATICS FROM THE UNIVERSITY OF PUGET SOUND AND A PH.D. DEGREE IN PHYSICS FROM OHIO STATE UNIVERSITY. HE IS A FELLOW OF BOTH THE AMERICAN PHYSICAL SOCIETY AND THE AMERICAN NUCLEAR SOCIETY AND SERVED FOR THREE YEARS ON THE ATOMIC ENERGY COMMISSION'S ADVISORY COMMITTEE ON REACTOR PHYSICS. IN RECENT YEARS, HE HAS SERVED ON SEVERAL INTERNATIONAL COMMITTEES AND RESEARCH PROJECT BOARDS THAT OVERSEE LARGE-SCALE COOPERATIVE SAFETY RESEARCH PROJECTS.

DR. LOEWENSTEIN WAS PRESIDENT (1989-1990) OF THE AMERICAN NUCLEAR SOCIETY AND SECRETARY/TREASURER (1990) OF THE AMERICAN ASSOCIATION OF ENGINEERING SOCIETIES.

DR. LOEWENSTEIN IS A MEMBER OF THE NATIONAL ACADEMY OF ENGINEERING.

Dr. Walter B. Loewenstein

## Education

| | |
|---|---|
| B.S. | University of Puget Sound (1949) |
| - | University of Washington (1949-1950) |
| Ph.D. | Ohio State University (1954) |

## Professional Record

| | |
|---|---|
| 1989 - Present | Energy Technology Consultant |
| 1973 - 1989 | Nuclear Power Division, EPRI |
| 1954 - 1973 | Argonne National Laboratory |
| 1950 - 1954 | Ohio State University; Texas Company Fellow<br>Vibrational analysis of large molecules |
| 1953 - Summer | Los Alamos Scientific Laboratory; Research Assistant, Thin films for accelerator experimentations |
| 1952 - 1953 | Ohio State University; Research Foundation Fellow, Analysis Optical interference filters |
| 1952 - Summer | Los Alamos Scientific Laboratory; Research Assistant, High Vacuum Technology |
| 1951 - 1952 | Ohio State University; Research Assistant, Experiments on optical interference filters |
| 1950 - 1951 | Ohio State University; Teaching Assistant, Optics Laboratory |

## Electrical Power Research Institute - Assignments

| | |
|---|---|
| 1981 - 1989 | Deputy Director, Nuclear Power Division (full-time in 1986) |
| 1973 - 1986 | Director, Safety Technology Department |

## Argonne National Laboratory - Formal Classifications

| | |
|---|---|
| 1973 | Director, Applied Physics Division |
| 1972 - 1973 | Director, EBR-II Project |
| 1968 - 1972 | Associate Director, EBR-II Project |
| 1963 - 1968 | Senior Physicist |
| 1956 - 1963 | Associate Physicist |
| 1954 - 1956 | Assistant Physicist |

014P/WBL/tbe

## ANL - Functional Assignments

| | |
|---|---|
| 1964 - 1968 | Chairman, EBR-II Irradiation Review Committee |
| 1972 - 1973 | ANL Professional Personnel Committee (member)\ |
| 1963 - 1973 | Chairman, ANL's Reactor Safety Review Committee |
| 1968 - 1973 | EBR-II Project |
| 1968 - 1972 | Associate Director of Analysis, EBR-II Project |
| 1966 - 1968 | Manager, Physics of LMFBR Program Planning |
| 1963 - 1966 | Manager, Fast Reactor Analysis |
| 1958 - 1963 | Project Physicist, EBR-II |
| 1954 - 1958 | Analysis of Fast Reactors & Critical Assemblies |

# RESUME

Loring E. Mills
Independent Consultant
132 Eareckson Lane
Stevensville, MD 21666

SUMMARY: Worked in industry for 43 years
Commercial Nuclear Programs - 31 years
Electrical Equipment Programs - 12 years

Twenty-seven years was as an employee of private industry in production centers outside of Washington, D.C., including five years at Hanford Laboratory. Sixteen years were applied on nuclear program policy issues at the Edison Electric Institute in Washington, D.C.

Retired from position of Vice President, Nuclear at Edison Electric Institute in March 1993

Providing Independent Consulting Services After March 1993

EDUCATION: BS Engineering - Union College, Schenectady, NY. - 1950
MBA - University of Washington, Seattle, WA - 1962

SPECIFIC WORK EXPERIENCE:

1976 to 1993 - Edison Electric Institute, Washington, D.C.

Coordinated the nuclear program efforts of EEI--building consensus positions among electric utilities with nuclear programs. Areas of primary emphasis included, nuclear fuel supply, uranium enrichment, nuclear waste disposal, nuclear plant Federal regulation, nuclear legislation, industry programs to improve the safe operation of nuclear plants and preparation of advanced standard nuclear energy plant designs for potential future application.

1971 to 1976 - Nuclear Fuel Services, Inc, - Rockville, MD

Served in several technical roles for NFS in the operation of facilities at West Valley, NY and Erwin, TN.
Developed a nuclear fuel supply program with anticipation of constructing both uranium and plutonium fuel production facilities at the West Valley site.
Design Project Manager for a facility to convert recovered urinal nitrate to $UF_6$ (not completed).
Co-authored the Environmental Impacts Statement prepared by NFS for the West Valley site.
Developed a Quality Assurance Program for both facilities.

1967 to 1971 - Kerr-McGee Corp. - Oklahoma City, OK

Project Manager for the design, construction and initial operation of a production plant for the conversion of low-enriched $UF_6$ to high integrity uranium ceramic fuel pellets. This plant produced uranium fuel for initial cores for several of the commercial nuclear energy plants that started operating in the early 1970s. Provided technical input for the design and construction of the Sequoyah $UF_6$ plant to convert yellow cake uranium concentrate to high purity natural $UF_6$.

1953 to 1967 - General Electric Company

Research, design and production functions were performed for GE at Electronics Park in Syracuse, NY, Hanford Laboratories in Richland WA, and General Purpose Control in Bloomington, IL. Specific assignments included; welding engineer, senior research engineer, chief metallurgist, and design department manager.

Materials and process support was provided for a wide range of civilian and military equipment being fabricated at Syracuse.

Research on metals and ceramics, along with process development for uranium and plutonium fuel materials was performed under the Plutonium Recycle Program at Hanford Laboratory.

Development, design and production management tasks were performed for a wide range of electro-mechanical equipment at the Bloomington plant.

1951 to 1953 - Bentley Machinery Company - Syracuse, NY

Engineering design and production tasks were performed for semi-automatic production equipment.

1950 to 1951 - New York Central Railroad - Albany, NY

Performed engineering tasks.

SIGNIFICANT ACCOMPLISHMENTS:

Five Patents

NYS Professional Engineering License

Prominent role in utility industry establishment of the Institute of Nuclear Power Operations

Held positions of Secretary and Treasurer for Advanced Reactor Corporation

General Chairman of the 1991 American Nuclear Society Winter Meeting

Five years on the UNLV Executive Committee for the Annual International Conference on Radioactive Waste Disposal

Committee Member for the industry Strategic Plan For Building New Nuclear Power Plants

Several industry presentations on the conversion of high-enriched uranium to commercial nuclear fuel

Initiated and led utility industry efforts for Federal Legislation on nuclear waste management and the transfer of responsibility for uranium enrichment to a separate Federal Corporation

Security Clearances: L and Q(U) with AEC, ERDA and DOE

# RESUME OF HENRY W. MORTON

**EDUCATION**

MS in Environmental Science, 1972
The University of Michigan
Emphasis in Radiological Science

BS in Nuclear Engineering, 1965
The University of Tennessee

**CURRENT POSITION**

Mr. Morton is a technical consultant in radiation protection and radioactive waste management with over 25 years of professional experience in the nuclear field in health physics, radioactive waste management, environmental aspects of nuclear power, nuclear licensing, nuclear criticality safety, and instrument and testing methods development. In October, 1982, Mr. Morton established an independent consulting practice through which he works both independently and cooperatively with associates in meeting the needs of clients.

**PROFESSIONAL EXPERIENCE**

Mr. Morton has experience in all steps of the nuclear fuel cycle other than uranium enrichment and HLW disposal. He has:

- prepared comments on proposed government regulations for industry associations;
- analyzed tailings disposal at a uranium mine and mill;
- led field investigation and characterization of radioactive waste at a natural thorium and uranium processing site;
- managed nuclear safety and licensing at a nuclear fuels plant;
- analyzed sediment ponds decommissioning and disposal alternatives at a nuclear fuels site;
- led a team that evaluated the nuclear criticality safety program at a nuclear fuel plant; and
- analyzed environmental impacts, nuclear criticality safety, and health physics aspects and participated in licensing of a nuclear fuel reprocessing plant.

At a $UF_6$ conversion plant, he:

- participated in independent oversight of operations and safety conditions;
- performed preliminary assessment of solid radwaste disposal alternatives;
- planned and initiated an evaluation of the health physics program;
- led an independent assessment of management; and
- led a review of health, safety, and environmental procedures and administrative controls and developed recommended improvements.

For nuclear power reactors, Mr. Morton has:

- performed health physics, environmental, and radwaste analyses and licensing;
- prepared and negotiated radioactive effluent and environmental technical specifications and offsite dose calculation manuals;
- analyzed power reactor radwaste treatment systems for ALARA radioactive effluent; and
- designed computer software to implement offsite dose calculations.

Mr. Morton has also consulted extensively to the fertilizer industry concerning uranium series radionuclides occuring naturally in phosphate.

In October, 1982, Mr. Morton established an independent consulting practice and was joined in May, 1984, by Thomas Potter, forming the firm, Morton and Potter. They practiced as an entity through 1990.

Mr. Morton was a Partner and Technical Manager in the consulting firm, Nuclear Safety Associates, from 1976 through 1982. With NSA, he provided consultation to industry in the areas of radiation protection, radioactive waste management, environmental assessment, and regulatory

affairs. His consulting activities included:

- evaluation of radwaste systems and the environmental impact of reactor effluents,
- analysis of low-level waste management alternatives,
- consulting in health physics and radiation protection programs,
- managing radiation surveys, and
- representing industry in regulatory and licensing proceedings.

Before joining NSA, Mr. Morton was an Environmental Protection and Licensing Specialist with Nuclear Fuel Services, Inc., from 1972 to 1976. In that capacity, he performed analyses of nuclear criticality, safety, radiation shielding, and environmental and radiological safety; and he developed safety design bases for fuel reprocessing, fuel fabrication, and UF6 plants.

Mr. Morton served as the Supervisor of Nuclear Criticality Safety and Licensing at the Nuclear Fuel Services, Inc., reactor fuels plant in Erwin, Tennessee for three years, from 1968 through 1970. There he directed the criticality control program, prepared license applications and supporting safety analyses, audited the radiation protection programs, and coordinated licensing and compliance activities for the plant.

Earlier, Mr. Morton worked at the Y-12 Plant in Oak Ridge, Tennessee. During two years of work there he developed instrumentation and measurement methods, and during another two years he worked in health physics, chemical processing, and engineering design.

AWARDS AND CERTIFICATIONS

Certified Health Physicist by the American Board of Health Physics.
Special Fellowship in Radiation Protection by the U.S. Atomic Energy Commission

PRESENTATIONS AND PUBLICATIONS

Lieberman, J.A., J.S. Bland, H.W. Morton, and W.A. Rodger, "Development of Recommended Regulatory Cutoff Levels for Low-level Radioactively Contaminated Oils from Nuclear Power Plants", UNWMG report, October 1983.

H. Morton, "Radiation Protection", Training Program presented to EDS Nuclear, Walnut Creek, Ca., March 1981.

Rodger, W.A., S Stanton, R. Frendberg, and H.W. Morton, "de minimus Concentrations of Radionuclides in Solid Wastes", AIF/NESP-016, April 1978.

H. Morton, "Radiological Impact Assessment of the Four-Corners Mine", NSA report, August 1977.

H. Morton and T. Wenstrand, "Analysis of Occupational Radiation Exposure History at a Nuclear Fuel Reprocessing Plant", presented at ANS Annual Meeting, 1976.

H. Morton, "Thermoelectric Refrigeration of Surface Barrier Detectors", ORTEC report, June 1965.

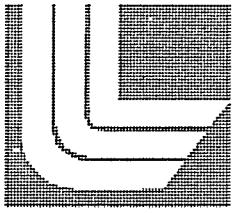
PERSONAL

US Government security clearance

# DEPLETED URANIUM HEXAFLUORIDE MANAGEMENT PROGRAM

Technology Assessment Project

**Independent Technical Review Manual**



Lawrence Livermore
National Laboratory

January 1995

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APPENDIX I: LIST OF RESPONSES TO THE FEDERAL REGISTER REQUEST FOR RECOMMENDATIONS

APPENDIX II: LIST OF INFORMATION PACKAGES

APPENDIX III: PRESENTATION MATERIAL

## 1.0 Mission

The Independent Technical Reviewers shall be outside technical experts with experience in one or more of the following: technology assessment, process technology, uranium processing and fabrication, R&D programs, engineering finance/economics, chemical process engineering, metallurgical process engineering, environmental engineering and waste management, hazards analysis (radiological, chemical, and physical/industrial), Nuclear Regulatory Commission (NRC) licensing, environmental permitting/environmental impact assessments, and regulatory issues. Most importantly, the Independent Technical Reviewers must be independent, that is to say free of any real, perceived, or potential, personal or organizational conflicts of interest to ensure no recommendation receives an unfair advantage.

The Independent Technical Reviewers will conduct independent and separate reviews of all recommendations received as a result of the Department's Request for Recommendations as well as other known technologies and uses. These reviews will be conducted separately, without input or consultation with other Independent Technical Reviewers or with employees of the Department of Energy. The Independent Technical Reviewers shall evaluate each recommendation individually to determine its merits and feasibility, in accordance with the evaluation factors established by LLNL and their own individual expertise. This evaluation should identify the benefits and drawbacks associated with the proposed technology or use, any noteworthy points which would not be evident to non-experts and any issues which could hamper its application.

LLNL is not seeking consensus of the Independent Technical Reviewers.

## 2.0 Evaluation Instructions

The evaluation factors contained in Section 3 are to be applied in evaluating proposed uses and management technologies for the Department's inventory of depleted uranium hexafluoride ($DUF_6$). Management technologies include any technologies that could be used in the storage, handling, transportation, conversion/transformation, or disposal of the material. These factors are based on the *Federal Register* notice of November 10, 1994 (Vol. 59, No. 217), in which the Department requested recommendations and asked that respondents provide as much information as possible on various aspects of the use and technology being recommended.

Reviewers should evaluate each response on its own merits, and not in comparison to other alternatives or recommendations. The factors identified in Section 3 should be viewed as guidelines, rather than as a formula by which to score the recommendations. The list of factors is intended to give the Reviewer a sense of the issues which are important for enabling the Department to determine whether or not the recommendations are reasonable. The Reviewer should particularly seek to identify and discuss the issues that may not be evident to nonexperts. The Reviewer should also note recommendations which are of particular merit.

Evaluations should be qualitative in nature and based on judgment born of the reviewer's special expertise and experience. Opinions should be clearly and substantially supported. Evaluations need not address every item in the list of factors if the reviewer believes that not all are relevant in each case. Moreover, the absence of a factor from the list below should not be taken to mean the factor is not important. In such a case, the reviewer should indicate the factor at issue, justify its inclusion, and include it in the evaluation.

Feasibility is a relative concept in this undertaking. A recommendation may not, in the end, be determined to be "reasonable" if it is only "feasible" under highly restrictive conditions. Where appropriate, include consideration of the probability of success within a reasonable time period. The Reviewer's professional judgment is particularly important in such matters, especially

where an inherent advantage of a recommendation is so significant that it merits special consideration with regard to "time to technical maturity."

Although the *Federal Register* notice instructed respondents to ignore regulatory restrictions, existing or likely, when recommending a use or technology, regulatory considerations are important in judging whether a recommendation is feasible or not. Should a response be of particular merit, however, the Department may wish to consider seeking to change the regulation.

## 3.0 Evaluation Factors

### 3.1 Development

Draft evaluation factors were developed by LLNL and provided through public information forums and a mailing to stakeholders for public comment. Comments were incorporated into the final factors.

### 3.2 Description

The following sections provide a brief description of the individual evaluation factors to be used by the Independent Technical Reviewers. These factors are presented in no particular order and no factor is considered to be of greater importance than another.

**Environmental, Safety and Health.** Consider the following issues of concern to workers, the public, and the environment:

- issues that may arise as the result of operations, transportation, handling, storage and disposal, including effluents and emissions.
- issues that may restrict site choices when constructing or operating a facility that employs this technology or application.
- design configurations, specifications, or operational requirements that pose problems of nuclear, chemical, or other safety issues involving workers or the public.

**Waste Management.** While this factor might well be included in Environmental, Safety and Health, its potential significance deserves special attention:

- radiological, non-radiological, hazardous, toxic, mixed or solid waste streams and waste volumes, or residual material that may pose problems of storage, transportation, treatment or disposal.

- potential for waste minimization in use or manufacture.
- potential for recycling.

**Costs.** Consider costs which are associated with the development or use of a technology or the use of a product, or which could preclude consideration of a recommendation.

- capital costs, both initial (including R&D) and continuing.
- annual operating and maintenance costs.
- decontamination and decommissioning costs.
- value of any product or facility salvage.
- cost avoidance through sale of any byproducts.

**Technical Maturity.** For technologies or uses that have no prior history, estimate the time-to-availability. Consider the probability of success. Which of the following developmental stages describes the technology:

- design - conceptual or detail
- bench or small scale
- developed but untested on a large scale
- tested or used on a large scale, but not standard industrial practice
- standard industrial practice

**Socioeconomics.** Consider the effects of the application of a product or the use of a management technology on the following:

- employment
- public acceptance
- local or regional development

**Other factors.** Add any other information believed pertinent to the feasibility of the submission.

## 4.0 Evaluation Process

### 4.1 Orientation.

Prior to commencing the review, the Independent Technical Reviewers will meet for an Orientation January 31 - February 1, 1995.

### 4.2 Scope

The Independent Technical Review is broken into two parts - evaluation of the recommendations received, and evaluation of other known technologies. Twenty-three submittals containing recommendations were received in response to the Request for Recommendations. These submittals included approximately 42 uses or technologies to be evaluated. A listing of these submittals is included in Appendix I. Additionally, the Department has identified all the known technologies and uses which need to be evaluated, which are listed in see Appendix II.

### 4.3 Request for Recommendation Submittals.

All the recommendations received in response to the Request for Recommendations are included in the *Responses to Request for Recommendations* binder. These recommendations include all the information provided in the response. Several submittals contain more than one recommendation -- an separate evaluation must be done for each individual recommendation included in each submittal.

### 4.4 Information Packages

The *Information Packages* binder contains information packages which provide supplemental information to assist in the evaluation of the recommendations. Additional

information packages will also be provided for the evaluation of known options identified by the Department for which no recommendation was received.

The Information Package is broken into two major sections - the Overview and Evaluation Factor Information. The Overview describes the process or use in detail, including the input materials, wastes and anticipated $DUF_6$ consumption. The Evaluation Factor Information identifies information which may have bearing on the Reviewers evaluation. Any references used in its development are listed at the end of the Information Package so that the Reviewers may locate the original source of the information if necessary.

### 4.5 Obtaining Documents for the Review.

If, during the course of the review, a Reviewer identifies a document which would be useful but is unable to obtain a copy, the Reviewer should get in touch with the appropriate point of contact identified in Section 4.8 for assistance. The Reviewer should provide the following information:

- the document title, and report number if applicable,
- the date of the document,
- the author, Government agency or company the report was generated by,
- the Information Package which the document is referenced, if applicable, and
- your name, phone number and address to which you would like the document sent.

LLNL will try to obtain a copy of the document for the Reviewer. Once the document is available, it will be sent to the requesting Reviewer by next day air. The points of contact have voice mail so a message may be left at any time of the day or night.

## 4.6 Guidelines for "Reasonable"

DOE will use the results of this review to determine whether each technology or use is "reasonable". In support of this determination, a general set of guidelines for *reasonability* have been formulated. These guidelines are presented below:

Timing - If an option will be operational (at full scale) within 10 years of initiation and complete within 30 years of becoming operational, the option would be considered reasonable with regard to timing.

Programmatic Impact - An option capable of realistically supporting the disposition of at least 15% of the Department's depleted uranium inventory (i.e., 84 metric tons) would be reasonable.

Environmentally Sensible - An option should not create waste streams of equal volume to the depleted uranium volume being dispositioned (as approximated by the Reviewers).

Cost - An option would be reasonable if its implementation cost is less than $5 billion (as approximated by the Reviewers).

Consistent Mission - The option should be consistent with comparable activities within the Department of Energy and other Federal agencies.

These guidelines should be used only for the purposes of this evaluation and are included so that the Reviewers may understand the areas of concern to the Department. The above guidelines are presented in no particular order and none are considered to be of greater importance than another.

## 4.7 Other Sources of Information

If a Reviewer identifies a point of contact which will be helpful in their review, this

resource may be used as long as the independence of the review is maintained. Therefore, the Reviewers are requested to abide by the following precepts:

- Do not contact other members of the Independent Technical Review group or any employees of the Department of Energy. This is to ensure the integrity of the independent review is maintained and the review does not become biased by the Department of Energy. If the Reviewer requires any information or specific documents from the Department, the Reviewer should contact either the appropriate point of contact identified in Section 4.8. LLNL will obtain the required information and pass it to the Reviewer as soon as possible.

- Identify to LLNL any other contacts made. This serves a dual purpose -- to monitor outside contacts made to ensure no conflicts of interest arise and to identify other sources of specific information which may be useful to other Reviewers as well. Reviewers should notify one of the Overall Program points of contact identified in Section 4.8 of all outside sources of information as early in their review process as possible.

### 4.8 Points of Contact

The following points of contact are available should the Independent Technical Reviewers have any questions or need any other assistance:

| | | |
|---|---|---|
| Overall Program:<br>(Procedures/protocol) | Scott Patton<br>Barry Smith | (301) 916-6702<br>(301) 353-8338 |
| Technical: | Stephen Krill | (301) 353-0157 |
| Documents | Ellen Elia | (301) 353-8232 |

### 4.9 Final Evaluation Report

Once you have completed your review, you should prepare a final evaluation report for each use or managment technology to return to LLNL. Figure A contains a sample format which the Reviewers may use for their evaluation. This is the preferred format and is included on the disks provided with this manual. All resources used in your evaluation must be referenced.

A hard copy of the report and the disks should be sent to LLNL in the care of:

Scott E. Patton
Lawrence Livermore National Laboratory
20201 Century Boulevard, 2nd Floor
Germantown, MD 20874

**ALL FINAL EVALUATION REPORTS ARE DUE BY APRIL 28, 1995**

## Sample Evaluation of Title of Technology or Use Option

**Information Package #**

**Reviewed by:** Reviewer's Name

**A. Environmental, Safety and Health.** Consider the following issues of concern to workers, the public, and the environment:

*- issues that may arise as the result of operations, transportation, handling, storage and disposal, including effluents and emissions.*

*- issues that may restrict site choices when constructing or operating a facility that employs this technology or application.*

*- design configurations, specifications, or operational requirements that pose problems of nuclear, chemical, or other safety issues involving workers or the public.*

**Response:**

**B. Waste Management.** While this factor might well be included in Factor A, its potential significance deserves special attention:

*- radiological, non-radiological, hazardous, toxic, mixed or solid waste streams and waste volumes, or residual material that may pose problems of storage, transportation, treatment or disposal.*

*- potential for waste minimization in use or manufacture.*

*- potential for recycling.*

**Response:**

**Figure A**

**C. Costs.** Consider costs which are associated with the development or use of a technology or the use of a product, or which could preclude consideration of a recommendation.

- *capital costs, both initial (including R&D) and continuing.*
- *annual operating and maintenance costs.*
- *decontamination and decommissioning costs.*
- *value of any product or facility salvage.*
- *cost avoidance through sale of any byproducts.*

**Response:**

**D. Technical Maturity.** For technologies or uses that have no prior history, estimate the time-to-availability. Consider the probability of success. Which of the following developmental stages describes the technology:

- *design - conceptual or detail*
- *bench or small scale*
- *developed but untested on a large scale*
- *tested or used on a large scale, but not standard industrial practice*
- *standard industrial practice*

**Response:**

**E. Socioeconomics.** Consider the effects of the application of a product or the use of a management technology on the following:

- *employment.*
- *public acceptance.*
- *local or regional development.*

**Response:**

**F. Other factors.** Add any other information believed pertinent to the feasibility of the submission.

**Response:**

**G. Conclusions.** Based on the evaluation above and the guidelines for establishing reasonability provided in the Independent Technical Review Manual, provide a determination as to whether or not this option is reasonable and a brief justification of this conclusion.

**Response:**

## 5.0 Importance of Maintaining Independence

The Technical Assessment Project was established to ensure that all proposals and known technologies received an impartial and objective review to determine feasibility and reasonableness. Therefore, it is essential that the Independent Technical Reviewers are free of bias and that the Reviewer, and the organization with which the Reviewer is associated, receive no unfair competitive advantage. Any association the Reviewer has with the industry and/or technology associated with the proposals must be sufficiently remote that there is no appearance of potential for personal or organizational gain.

Furthermore, the Independent Technical Reviewers must maintain their integrity throughout the review process by not exchanging information with each other or interacting with the Department of Energy. The Reviewer may contact any other resource he or she may know, however the Reviewer should inform LLNL of outside contacts made. Should a Reviewer require additional information to assist the review, he or she should contact the appropriate individual(s) identified in Section 4.8.

## 6.0 Handling Proprietary Data

Some of the recommendations submitted per the Request for Recommendations contained proprietary information. Therefore, the Independent Technical Reviewers will be required sign a Confidentiality and Conflict of Interest Certificate (Figure B) before they can review these submittals.

If any questions arise throughout the course of the review pertaining to the handling or use of this proprietary data, the Reviewer should contact the Overall Program point of contact identified in Section 4.8.

UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE NATIONAL LABORATORY

## CONFIDENTIALITY AND CONFLICT OF INTEREST CERTIFICATE

In anticipation of my participation in the evaluation of recommendations submitted in response to Request for Recommendations (59 FR 56324) for the Depleted Uranium Hexafluoride Management Program subcontract, I certify that I will not disclose, except pursuant to applicable law or regulation or the order of a court of competent jurisdiction, any information either during the proceedings of the evaluation or any subsequent time concerning the evaluation to anyone who is not also authorized access to the information in accordance with the policies of the University, law or regulation, and only then to the extent that such information is required in connection with such person's official responsibilities. Furthermore, I will report to the Task Manager any communication concerning the procurement or the committee's composition and activities directed to me from any source outside the committee.

I also certify that:

1. I shall not use *"privileged information"* acquired through participation for personal gain.

2. I am not aware of any matter which might reduce my ability to participate in the evaluation proceedings in an objective and unbiased manner, or which might place me in a position of conflict, real or apparent, between my responsibilities as an evaluator and other interests.

   In making the certification I have considered all my financial interests and employment arrangements, including those of my spouse, minor children, and other members of my immediate household.

3. If, after the date of this certification, any person, firm, or organization with which, to my knowledge, I (including my spouse, minor children, or members of my immediate household) have a financial interest or with which I have an employment arrangement, submits a proposal or otherwise becomes involved in this procurement, I will so notify the Task Manager. Unless advised otherwise, I will not participate further in the evaluation.

4. Neither I, my spouse, minor children, or members of my immediate household will accept anything of monetary value from any person, firm, or organization seeking to do business with the University through this solicitation. (Even seemingly trivial courtesies can present the appearance of impropriety or create a subtle sense of obligation and so must be avoided.)

Signature: _____

Name: _____

Date: _____



Figure B

## 7.0 Protocol

# *DO ...*

... CONTACT ANY COLLEAGUES, ASSOCIATES, ETC. WHICH CAN PROVIDE YOU INFORMATION TO ASSIST YOUR REVIEW -- BUT BE SURE TO NOTIFY THE APPROPRIATE POINT OF CONTACT AT LLNL AHEAD OF TIME TO ENSURE NO CONFLICTS OF INTEREST EXIST.

... ADDRESS ANY OTHER INFORMATION RELATING TO THE DEPLETED URANIUM TECHNOLOGIES OR USES WHICH MAY BE RELEVANT BUT ARE NOT INCLUDED IN THE EVALUATION FACTORS.

... IT IS NOT NECESSARY TO COMMENT ON ANY EVALUATION FACTORS WHICH YOU DO NOT FEEL ARE WITHIN YOUR REALM OF EXPERTISE OR EXPERIENCE -- HOWEVER, ANY "COMMON SENSE" ANSWERS OR COMMENTS ARE WELCOME, AS LONG AS THEY ARE IDENTIFIED AS SUCH.

... IDENTIFY ALL REFERENCES USED IN YOUR RESPONSE.

... NOTIFY THE POINTS OF CONTACT IDENTIFIED IN SECTION 4.8 WHEN YOU USE SOURCES THAT YOU BELIEVE WOULD ASSIST OTHER REVIEWERS.

... CALL THE POINTS OF CONTACT IDENTIFIED IN SECTION 4.8 IF YOU NEED ASSISTANCE OBTAINING A SPECIFIC DOCUMENT.

# *DON'T ...*

... CONTACT DOE FOR ANY REASON.

... CONTACT OTHER INDEPENDENT TECHNICAL REVIEWERS DURING THE REVIEW.

... WRITE A FULL "DISSERTATION" ON THE PROPOSED DEPLETED URANIUM TECHNOLOGIES OR USES. PLEASE TRY TO LIMIT YOUR RESPONSES TO A MAXIMUM 300 WORDS PER EVALUATION FACTOR.

... REVEAL ANY INFORMATION IDENTIFIED AS PROPRIETARY TO ANYONE OUTSIDE THE REVIEW.

# DEPLETED URANIUM HEXAFLUORIDE MANAGEMENT PROGRAM
## Independent Technical Review of Responses to Request for Recommendations for Depleted Uranium Hexafluoride (59 FR 56324)

| Doc # | Date Submitted | Contact | Recommendations | Package # |
|---|---|---|---|---|
| 1 | 11/23/94 | Mr. A.N. Tschaeche<br>1693 Claremont Lane<br>Idaho Falls, Idaho 83404 | The material should be left in present form at the current sites and used to make blanket material for breeder reactors for generating electricity and plutonium for use in electric generating nuclear power plants. | D1<br>E1 |
| 2 | 11/26/94 | Mr. Mark Strauch<br>48 Glacier Place<br>Livermore, California 94550 | Enough depleted uranium should be retained to:<br>1.Blend down HEU from retired nuclear weapons to reactor fuel levels of enrichment.<br><br>2.Blend down HEU from both retired Former Soviet Union (FSU) weapons and any stockpiles of HEU that exist in FSU states.<br><br>3.Used in MPC design for the storage and disposition of spent nuclear fuel and other high level nuclear waste.<br><br>4.Reduce UF6 to metal state for long term safety and management. | 1) G1<br><br>2) G1<br><br>3) I1<br><br>4) C3 |
| 3 | 12/2/94 | Mr. Bert Jody, Jr.<br>President<br>Davis Transport<br>Box 1139<br>1345 S. 4th Street<br>Paducah, Kentucky 42002-1139 | Transporter of natural UF6 for Allied and Cameco and DUF6 for DOD.<br><br>Gave opinions on different processes:<br>1. Oxide reduction program offered by Allied/GA is a real option and the price is right<br><br>2. Reduction to metal for at least part of the stockpile through CMI at Barnwell, SC | <br><br><br><br>1) 2<br><br>2) 3 |
| 4 | 12/5/94 | Mr. William Quapp<br>Idaho National Engineering Laboratory<br>P.O. Box 1625<br>Idaho Falls, Idaho 83415 | Potential uses:<br>1.Advanced spent nuclear fuel shielding material (ducrete) for MPC or MRS<br><br>2.Depleted uranium based energy storage flywheels<br><br>3.Conversion to metal using INEL plasma process and use as feedstock for AVLIS enrichment process<br><br>Technologies:<br>1.Produce stabilized uranium oxide "rock" that could be disposed directly at sites requiring stabilization | 1) B2<br><br>2) J1<br><br>3) 4, H1<br><br><br>1) A1, A3 |
| 5 | 12/9/94 | Mr. Frank Warner<br>General Atomics<br>3550 General Atomics Court<br>San Diego, CA 92121-1194<br><br>Mr. Sanford Rock<br>Allied Signal, Inc.<br>P.O. Box 8005<br>Morristown, NJ 07962-8005 | GA-Sequuoyah Fuels/ASI offers a method for DUF6 disposition based on a GA patent for UF6-to-U3O8 conversion processing that will produce commercially valuable anhydrous hydrogen fluoride (AHF) as a co-product. R&D complete, demo $20-$50M and 2-3 years, scale plant $80-100M. Private conversion, transportation, depreciation, D&D cost ~ $1/lb DUF6. | 2 |
| 6 | 12/9/94 | Mr. Frank A. Shallo<br>COGEMA, Inc.<br>7401 Wisconsin Avenue<br>Bethesda, MD 20814-3416 | Conversion to $U_3O_8$ for safe long-term storage, pending future decisions concerning reuse or disposal. Recycle of aqueous HF into commercial market. Open to joint venture. | 1 |

| Doc # | Date Submitted | Contact | Recommendations | Package # |
|---|---|---|---|---|
| 7 | 12/9/94 | Mr. A.N. Tschaeche<br>1693 Claremont Lane<br>Idaho Falls, Idaho 83404 | Use as blanket material for breeder reactors. Continue with current storage and management practices (no action). Don't do EIS until breeder reactor program. See comments on 11/23/94. | C2<br>D1<br>E1 |
| 8 | 12/10/94 | Mr. Dennis R. Floyd<br>Manufacturing Sciences Corporation<br>3265 Fenton Street<br>Denver, CO 80212 | Submitted proposed Cooperative Research and Development Agreement (CRADA) for direct reduction of UF6 to U metal, by-passing the UF4 stage and eliminating $MgF_2$ LLW. The technique involves reduction by hydrogen in a high temperature plasma. Use DU metal for shielding applications. LANL has yet to fund CRADA. Need pilot (3 yrs and $12M) and demonstration facility. Full scale facility $1.10/lb DUF6 processed. | 4 |
| 9 | 12/10/94 | Mr. Patrick F. Brown<br>113 Columbia Drive<br>Oak Ridge, TN 37830 | Recover fluorine for beneficial use. Recover $^{238}U$ for use in breeder reactors and recover $^{235}U$ for SWU value, storing both as oxides. Store oxide in Cor Ten steel boxes made from cylinders. Evaluate direct conversion to fluorine compounds and uranyl nitrate, then denitrate. Evaluate emulsion phase contactors for isotope separation of uranyl nitrate. Recommends specific safety precautions for handling material. | New info package<br><br>D1<br>E1 |
| 10 | 12/12/94 | Mr. Alan Waltar<br>American Nuclear Society<br>555 North Kensington Avenue<br>La Grange Park, IL 60525 | Most cost efficient method for management of DUF6 is to continue the present mode of storage. Use DUF6 as blanket material to make fuel in breeder reactors - the amount of energy produced would exceed that available from all the oil under the Saudi peninsula. | C2<br>D1<br>E1 |
| 11 | 12/15/94 | Mr. Steven T. Carter<br>Ohio Valley Regional Development Commission<br>740 Second Street<br>Room 102<br>Portsmouth, Ohio 45662-4088 | 1.Consider whether the stored cylinders could be further depleted by refeeding them back into the cascades.<br><br>2.Utilizing AVLIS technology which may decrease the amounts of U-235 remaining in the depleted UF6. | 1) H2<br><br>2) H1 |
| 12 | 12/19/94 | Mr. Jeffrey R. Williams<br>Engineering Division<br>Department of Energy | Use metal to support OCRWM MPC program and the General Atomics (GA 4/9) truck cask subsystem which relies on DU as a shielding material. Potential uses for DU metal in MPC are in shield plug and as gamma shielding material in transportation cask. Will definitize requirement for MPC by Spring 1996. | I1 |
| 13 | 12/27/94 | Mr. Charles R. Schmitt<br>110 Adelphi Road<br>Oak Ridge, TN 37830 | Convert the UF6 to the stable and non-corrosive uranium trioxide (UO3) form by first reacting the UF6 with water to form uranyl fluoride (UO2F2) and hydrogen fluoride (HF) then precipitating the UO3 by the addition of lime. | New info package |
| 14 | 1/3/95 | Mr. Robert Bernero, Director<br>Office of Nuclear Material Safety and Safeguards<br>United States Nuclear Regulatory Commission<br>Washington, D.C. 20555-0001 | Believe that conversion to U3O8 and placement of the material in a mined cavity is one long term management option that should be included. State that although limited quantities could go in near surface disposal facility, these large quantities indicate the need for a unique disposal facility. | A1 |

| Doc # | Date Submitted | Contact | Recommendations | Package # |
|---|---|---|---|---|
| 15 | 1/5/95 | Mr. Charles Montford<br>GenCorp Aerojet<br>P.O. Box 399<br>Jonesborough, TN 37659<br><br>(submittal by Aerojet Ordnance Tennessee (AOT) and Babcock & Wilcox (B&W)) | 1. B&W/AOT team propose to reduce the DUF6 to DUF4 and then to metal (using unspecified process) then further process into products and/or storage.<br><br>2. Identifies several existing or potential products and markets:<br>Munitions, bomb door reinforcement, shape charge devices and drill collars for petroleum industry, storage or shipping devices for radioactive/ hazardous waste, navy ballast/other ballast and kinetic energy storage devices (power storage/flywheels), recovery of $^{235}U$ using AVLIS.<br>3. Recommends storing or disposing of unused DUF6 as U3O8 or metal (their preference). | 1) 3<br><br>2) J1, H1<br><br>3) A1, C1, A2 |
| 16 | 1/5/95 | Corrine Whitehead<br>Coalition for Health Concern<br>Route 9, Box 25<br>Benton, KY 42025 | Recommend "waste" be stored onsite in above ground earthquake-proof concrete structures. Want relocation of residents adjacent to facility; clean-up and stabilization of site, restricted access in perpetuity. | C2 |
| 17 | 1/5/95 | Mr. N. Dean Eckhoff<br>Kansas State University<br>137 Ward Hall<br>Manhattan, Kansas 66506-2503 | Fuel for reactors for production of electricity. Convert to an oxide and store for use as an energy source. | New info package |
| 18 | 1/6/95 | Mr. Thomas McWilliams<br>Chief, Life Cycle Readiness Division<br>Department of the Army<br>U.S. Army Production Base Modernization Activity<br>Picatinny Arsenal, New Jersey 07801-5000 | Working with DOE EM-50 (Cooley) for approximately 18 months. Presented 3 proposals, but has received no response. Unaware that DOE and LLNL were preparing FR notice.<br>3 uses proposed:<br>DU drill collars<br>DU well penetrator<br>DU well shape charge perforator | J1 |
| 19 | 1/7/95 | Dr. Velma Shearer<br>124 Chestnut Street, #210<br>Englewood, Ohio 45322 | Construction of at least 2 centers - fluorides could be sold for other industrial uses, and depleted uranium metal mixed with concrete slurry or sand to a natural background level of radioactivity and returned to or deposited in abandoned uranium mines. | C2, I1, I2, J1 |
| 20 | 1/8/95 | Mr. Ronald Lamb<br>Lamb Wheel Alignment<br>10990 Ogden Landing Road<br>Kevil, KY 42053 | On-site storage if UF6 is placed in above ground earthquake proof non-corrosive concrete structures. The waste must be stored to cause no additional exposure during seismic activity and should be high enough off ground to be monitored for surface leaks and radioactive releases. Also, public warning systems should be in place if a release should occur.<br><br>DOE reservation and adjacent lands on the West Kentucky Wildlife Refuge should be stabilized and cleaned up. Area residents should be offered the choice of relocation and should be compensated for the damage to their lands and homes. | C2 |

| Doc # | Date Submitted | Contact | Recommendations | Package # |
|---|---|---|---|---|
| 21 | 1/9/95 | Mr. Peter L. Lenny<br>Director, Marketing International<br>Cameco Corporation<br>2121 - 11th Street West<br>Saskatoon, Saskatchewan<br>Canada S7M1J3 | Conversion to $U_3O_8$ using defluorination or conversion to metal. Recovery of AHF which could be used in Cameco's own conversion operations or sold.<br><br>Three options are proposed:<br>1)Convert to $U_3O_8$ or $UO_2$ using multi-stage pyrohydrolyis with steam and hydrogen or ammonia.<br><br>2) Convert to $U_3O_8$ using sulphuric acid in Cameco defluorination process (patent pending).<br><br>3)Convert to metal using U-Metal/$MgSO_4$-Process. Conversion process for production of AHF from $MgF_2$ is similar to 2).<br><br>All yield AHF. | 1) 2<br><br>2) new info package<br>3) 3 |
| 22 | 1/9/95 | Dr. Charles Forsberg<br>Oak Ridge National Laboratory<br>P.O. Box 2008<br>Oak Ridge, Tennessee 37831 | Make Small DU vorosilicate glass beads for backfill material inside repository waste packages containing LWR SNF.<br><br>Potential benefits are:<br>1) Lower radionuclide release rates from the waste package over geological time due to slower dissolution of uranium oxide in fuel elements, lower hydraulic conductivity<br><br>2)Avoidance of nuclear criticality over geological time due to ion-exchange between U in glass and U in fuel rod<br><br>3) Lower radiation levels as a result of U glass shielding<br><br>4) Disposition of DU<br><br>5) Increased mechanical stability and thermal conductivity | New info package |
| 23 | 1/12/95 | Mr. Jerry Hutchison<br>Operational Quality<br>R&R International, Inc.<br>1234 S. Cleve.-Mass. Road<br>P.O. Box 4383<br>Akron, OH 44321 | Four small businesses collectively developed a 5 phase process to site a temporary storage facility for the $UF_6$ tails to be used until final repositories and reprocessing centers are available. Utilization of existing waste transfer and storage technologies at an upgraded and expanded privately owned licensed facility that has been operated by Nuclear Transport and Storage, Inc in McCracken Co., KY. Co-locating with possible oxide conversion plant proposed by Allied/Signa conceivable. | C1, C3 |

# Depleted Uranium Management Program -- Technology Assessment Information Packages

| Form of Depleted Uranium | Technology | Use |
|---|---|---|
| $U_3O_8$ | 1. Aqueous HF<br>2. Anhydrous HF | A1. Disposal<br>B1. DUcrete<br>C1. Storage |
| DU Metal | 3. Improved AMES<br>4. Plasma<br>5. Molten Salt | A2. Disposal<br>E1. IFR Fuel<br>H1. Re-Enrichment<br>I1. Shielding<br>J1. Products |
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| $UF_6$ | | C2. Storage<br>G1. Blending<br>H2. Re-Enrichment |

# Depleted Uranium Hexafluoride Management Program

# Independent Technical Review

**January 31 - February 1, 1995**
**Oak Ridge, TN**

# Participants

## Independent Technical Reviewers

- Mary Glass
- Brian Hajek
- Walter Loewenstein
- Lorning Mills
- Henry Morton

## Program Staff

- Scott Patton
- Barry Smith
- Alex Murray
- Ellen Elia

# Meeting Objectives

- Program Overview
- Mission of Independent Technical Reviewers
- Evaluation Factors
- Review Material
- Conducting Reviews
- Reporting

# Agenda - Tuesday, January 31

| | |
|---|---|
| 8:00 | Welcome and Introductions |
| 8:15 | Program Overview |
| 8:45 | Project Overview |
| 9:15 | Independent Technical Review |
| 10:15 | Break |
| 10:30 | Evaluation Factors |
| 11:00 | Review Materials |
| 11:30 | Evaluation Reporting |
| 12:00 | Lunch |
| 1:00 | Technical Review |
| 5:00 | Wrap-up |

# Agenda - Wednesday, February 1

**8:00** Tour of Y-12 Fabrication Facility

**11:00** Lunch

**12:00** Lessons Learned

**4:00** Adjourn

# Program Overview

# Background

- Depleted Uranium Hexafluoride ($UF_6$) is a byproduct of the enrichment process used to increase the Uranium-235 isotope in uranium material
- DOE currently has an inventory of approximately 560,000 metric tons of depleted $UF_6$ from the enrichment plants it ran over the last 5 decades

# Characteristics of Depleted UF6

- Forms a white, crystalline solid when stored at temperatures below 133 degrees Fahrenheit at atmospheric pressure
- Slightly less radioactive than natural uranium
- Forms uranyl fluoride ($UO_2F_2$) and hydrogen fluoride (HF) when exposed to water vapor

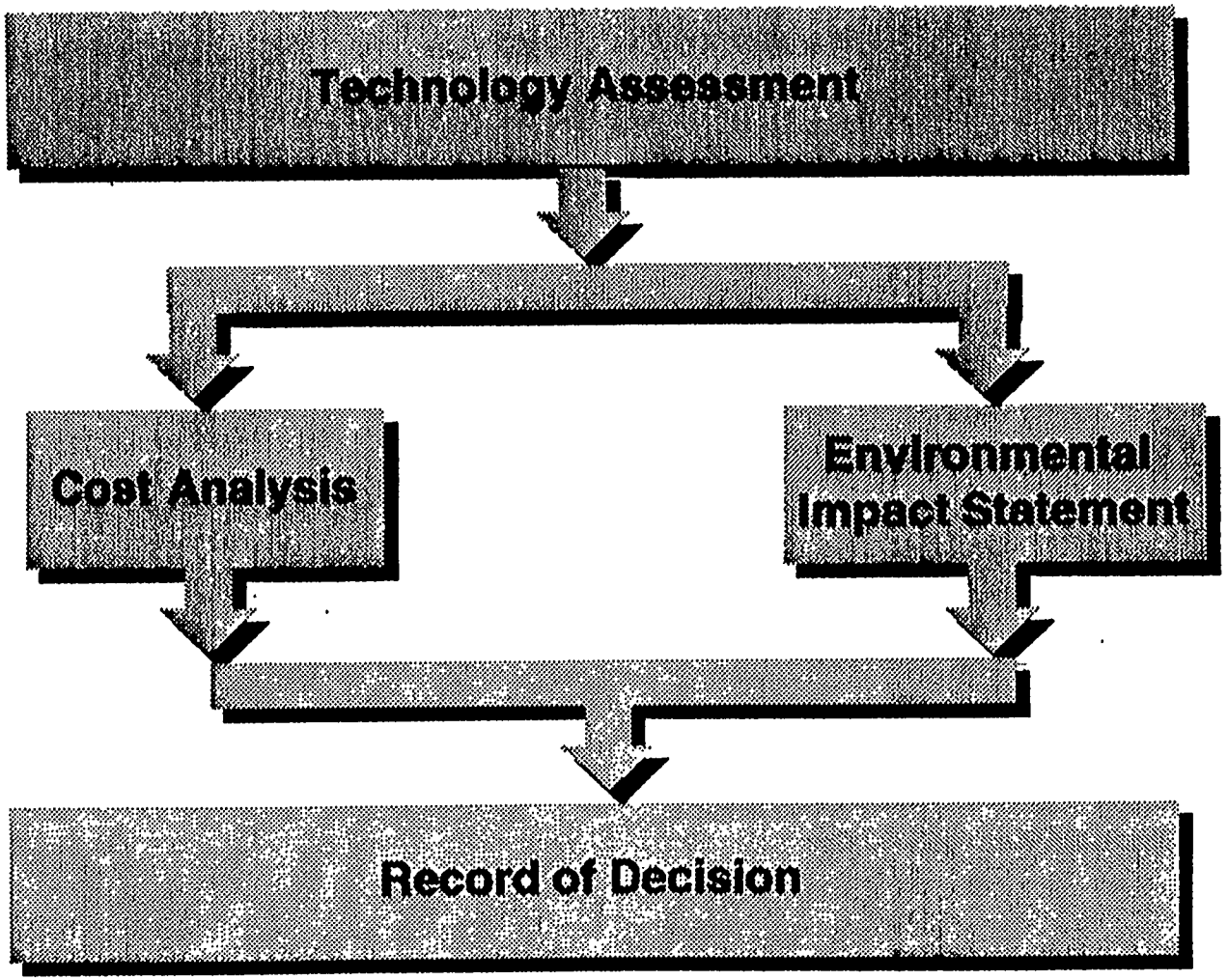
# Depleted Uranium Hexafluoride Management Program

- Current management practices
- Development of long-term strategy

# Components of Program

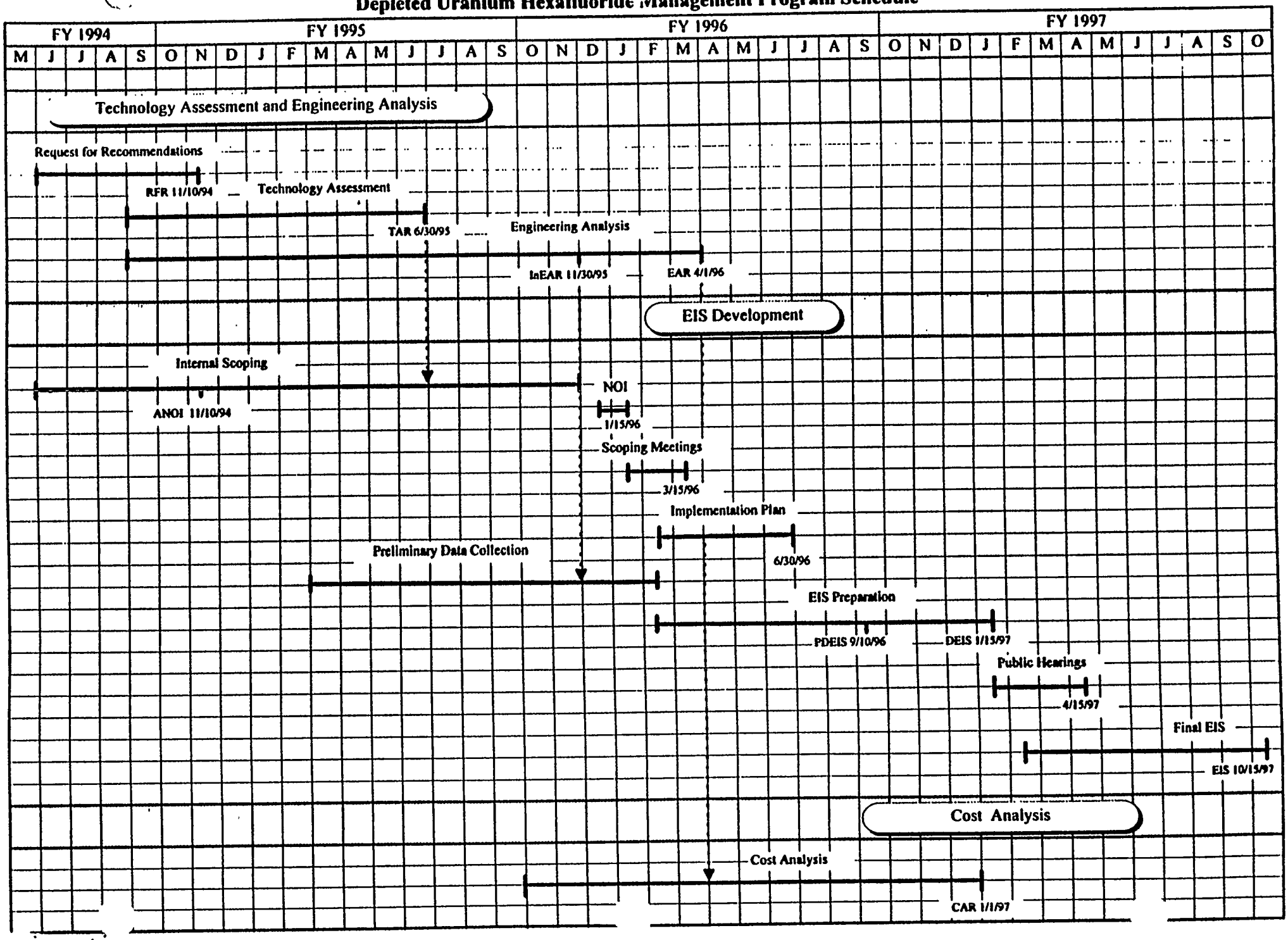
- Technical Assessment Project
- Engineering Analysis Project
- Environmental Impact Statement
- Cost Analysis Project
- Public Participation

# Program Overview



# Depleted Uranium Hexafluoride Management Program Schedule

1/24/95



# Technology Assessment Project

- **Goal: Provide DOE with information in order to identify those options which are technically feasible to consider in selecting the optimum long-term management strategy for depleted $UF_6$ stored.**
- **Three project elements:**
  - **Request for Recommendations**
  - **Independent Technical Review**
  - **Technology Assessment Report**

# Request for Recommendations

- Solicit input, recommendations and comments for potential uses of depleted $UF_6$ and for technologies that could facilitate its ultimate disposition or long-term management
- Sub-elements
  - RFR published in Federal Register on November 10, 1994
  - Direct mailing program to interested persons, industry, academic institutions, and governmental agencies
  - 60-day response period
  - Public informational forums

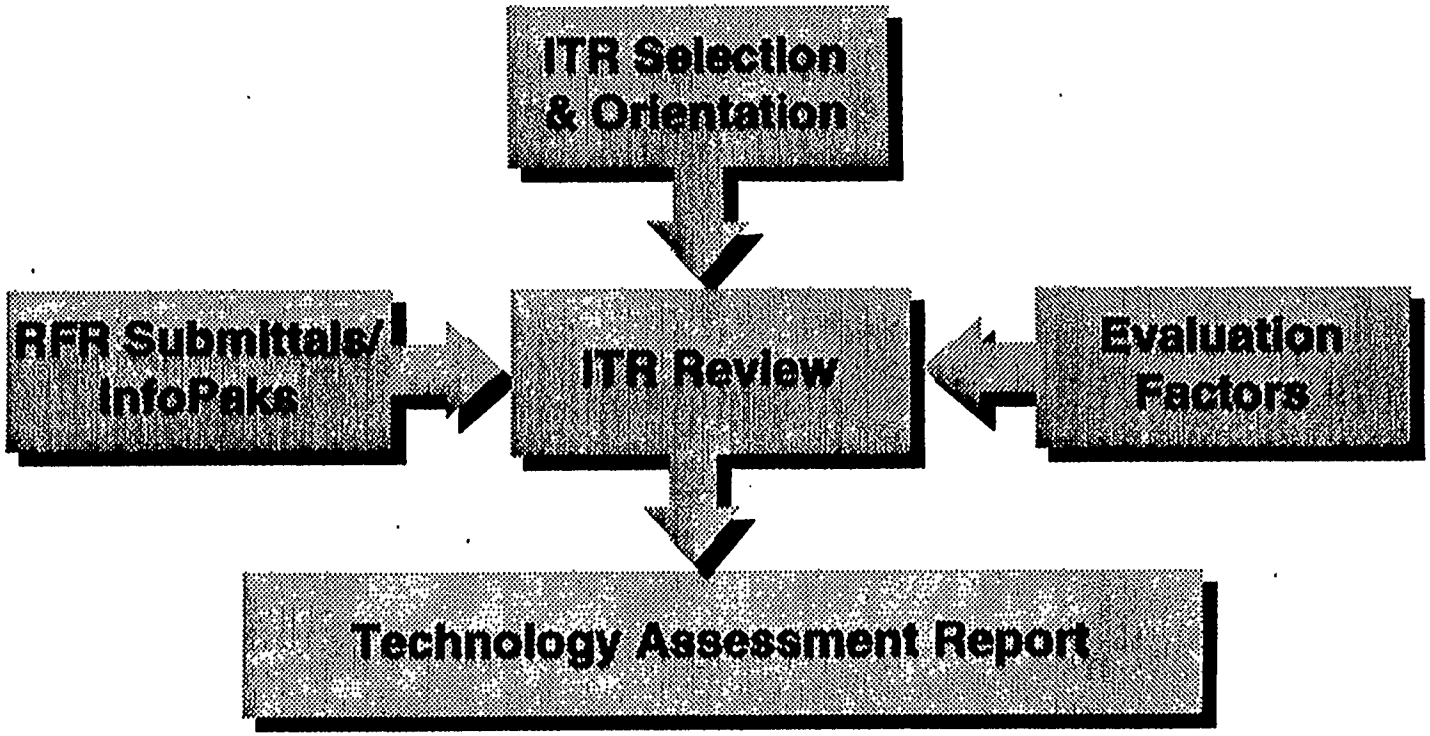
# Independent Technical Review

- Provide evaluation of technical feasibility of options identified through RFR process
- Use independent and qualified experts as reviewers
- Evaluation factors as guidance

# Technology Assessment Report

- Documentation of review
- Recommendations
- Responses to RFR

# Evaluation Process



# Independent Technical Review

# Mission

- Provide DOE with information to identify alternative management strategies
- To conduct reviews of all available options to determine their feasibility
- Evaluations should be qualitative in nature -- should not be a comparison of one option over another

# Composition

| ITR SELECTION CRITERIA | Technology Assessment | Process Technology (chemical, metallurgical) | Uranium Utilization | Research & Development Programs | Engineering Finance/Economics | Engineering Technology & Waste Management | Hazards Analysis | Licensing/Environmental Permitting | Environmental Impact Assessment | Regulatory Issues |
|---|---|---|---|---|---|---|---|---|---|---|
| DOE Experience Scientific Organization | | | | | | | | | | |
| Academia | | | | | | | | | | |
| Commercial/ Business | | | | | | | | | | |
| Nuclear Industry | | | | | | | | | | |
| Specialist | | | | | | | | | | |

# Importance of Independence

- Must ensure all options receive an impartial and objective review
- Maintain credibility of review
- Therefore, reviewers must:
  - be free of any bias
  - have no potential for personal or organizational gain
  - not exchange information with each other or outside parties once the review has begun
- Reviewers should address any questions or requests for additional information to the LLNL Task Manager

# Evaluation Instructions

- Evaluate each response on its own merits
- No comparisons to other responses
- Seek to identify and discuss the issues that may not be evident to nonexperts
- Note recommendations which are of particular merit
- Evaluations should be qualitative in nature
- Based on judgment born of Reviewer's special expertise and experience
- Opinions should be clearly and substantially supported

# Evaluation Factors

# Evaluation Factors

- Provided as guidelines for conducting the assessments
- Intended to give the Reviewers a sense of the issues important to DOE
- Public input

# Environmental, Safety & Health

- **Issues of concern to workers, the public and the environment in the following areas:**
  - **issues that may arise as a result of operations, transportation, handling, storage and disposal of depleted UF6, including effluents and emissions**
  - **issues that may restrict site choices when constructing or operating a facility that employs this technology or application**
  - **design configurations, specifications, or operational requirements that pose problems of nuclear, chemical, or other safety involving workers or the public**

# Waste Management

- Although this factor may be addressed as part of Environmental, Safety and Health, its potential significance deserves special attention.
- Consider the following:
  - Radiological, non-radiological, hazardous, toxic, mixed or solid waste streams and waste volumes, or residual material that may pose problems of storage, transportation, treatment or disposal
  - Potential for waste minimization in use or manufacture
  - Potential for recycling

# Costs

- **Consider the costs associated with the development or use of a technology or the use of a product, or which could preclude consideration of an option**
  - **capital costs, both initial (including R&D) and continuing**
  - **annual operations and maintenance costs**
  - **decontamination and decommissioning costs**
  - **value of any product or facility salvage**
  - **cost avoidance through the sale of any byproducts**

# Technical Maturity

- For technologies or uses which have no prior history, estimate the time-to-availability
- Consider the probability of success
- Identify the developmental stage which describes the technology
  - Design - conceptual or detail
  - Bench or small scale
  - Developed but untested on a large scale
  - Tested or used on a large scale, but not standard industrial practice
  - Standard industrial practice

# Socio-economic factors

- **Consider the effects of the application of a product or the use of a management technology on:**
  - **employment**
  - **public acceptance**
  - **local or regional development**

# Other factors

- **The Reviewers are encouraged to identify and discuss issues not addressed by the previous criteria which apply to an option and may not be evident to non-experts.**

# Assessment of Reasonableness

- **Timing**
  - Will be operational (at full scale) within 10 years of initiation
  - Will be complete within 30 years of becoming operational
- **Programmatic Impact**
  - Realistically supports disposition of at least 15% of DOE's depleted $UF_6$ inventory (84 metric tons)
- **Environmentally Sensible**
  - Waste stream is of less volume than depleted $UF_6$ inventory
- **Cost**
  - Should be less than $5 billion to implement
- **Consistent Mission**
  - Must be consistent with comparable activities within the Department of Energy and other Federal agencies

# Review Material

# Responses to Request for Recommendations Notebook

- Contains responses to the RFR and includes all information provided
- Table of contents identifies the individual submittals and itemizes the recommendations contained therein

# Information Packages

- **Individual package developed for each "known" technology or use and RFR recommendations**
- **Provide supplemental information for responses to the RFR**
- **Contains two sections:**
  - **Overview**
    - » describes the process or use in detail
    - » discusses input materials, wastes, anticipated DU consumption
  - **Evaluation Factor Information**
    - » identifies any available information on the process or use that pertains to specific evaluation factors

# Summary of Information Packages

| FORM | TECHNOLOGY | USE |
|---|---|---|
| $U_3O_8$ | 1. Aqueous HF<br>2. Anhydrous HF | A1. Disposal<br>B1. DUcrete<br>C1. Storage |
| DU Metal | 3. Improved AMES<br>4. Plasma<br>5. Molten Salt | A2. Disposal<br>E1. IFR Fuel<br>H1. Re-Enrichment<br>I1. Shielding<br>J1. Products |
| $UO_2$ | 6. Dry Conversion<br>7. Ammonium Diuranate (ADU)<br>8. Ammonium Uranyl Carbonate (AUC)<br>9. Gelation | A3. Disposal<br>B2. DUcrete<br>D1. MOX Fuel |
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| $UF_6$ | | C2. Storage<br>G1. Blending<br>H2. Re-Enrichment |

# Evaluation Reporting

# Report Format

- Number of responses
- Quantity and quality of information
- Reviewer's expertise
- Focus on mission of Independent Technical Review
- Sample evaluation document
- Format provided
- Conclusions

**ALL FINAL EVALUATION REPORTS ARE DUE APRIL 28, 1995**

# DEPLETED URANIUM HEXAFLUORIDE MANAGEMENT PROGRAM
## Technology Assessment Project

### Information Packages
### Table of Contents


| | |
|---|---|
| Information Package 1 | Defluorination Producing $U_3O_8$ and an Aqueous HF By-Product |
| Information Package 2 | Defluorination Producing $U_3O_8$ and an Anhydrous HF By-Product |
| Information Package 3 | Improved Ames Process |
| Information Package 4 | Plasma Reduction of $UF_6$ to Metal |
| Information Package 5 | Continuous Metallothermic Reduction to Uranium Metal |
| Information Package 6,7,8 | Conversion to Ceramic $UO_2$ - Existing Industrial Routes |
| Information Package 9 | Conversion to Ceramic $UO_2$ - Gelation |
| Information Package 10 | Conversion to Uranium Carbide - Combination Package of Graphite and Gelation Approaches |
| Information Package A1 | Disposal of $U_3O_8$ |
| Information Package A2 | Disposal of Depleted Uranium Metal |
| Information Package A3 | Disposal of $UO_2$ |
| Information Package B1 | Ducrete Using $U_3O_8$ |
| Information Package B2 | Ducrete Using $UO_2$ |
| Information Package C1 | Storage of $U_3O_8$ |
| Information Package C2 | Storage of $UF_6$ |
| Information Package D1/E1 | Potential Use of Depleted Uranium as Fuels in Thermal and Breeder Reactors |
| Information Package F1 | HTGR Fuel Fabrication Using Uranium Carbide |
| Information Package G1 | HEU Blending Using Depleted $UF_6$ |

| | |
|---|---|
| Information Package H1 | DU Re-Enrichment: AVLIS Technology |
| Information Package H2 | Uranium Re-Enrichment: Centrifuge |
| Information Package I1/I2 | Shielding Using DU Metal or Uranium Carbide |
| Information Package J1 | Dense Material Applications |

# INFORMATION PACKAGE
# 1

# Defluorination Producing $U_3O_8$ and an Aqueous HF By-Product

This Information Package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on Depleted $UF_6$ technologies or applications currently under consideration by the Department of Energy. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; it is intended to provide sufficient information to assist the Independent Technical Reviewer.

# *DEFLUORINATION PRODUCING $U_3O_8$ AND AN AQUEOUS HF BY-PRODUCT*

## 1. OVERVIEW

This information package briefly describes the conversion of depleted uranium hexafluoride ($UF_6$) to triuranium octaoxide ($U_3O_8$) using a defluorination process that produces an aqueous hydrogen fluoride (HF) by-product. It also provides supplemental data on environment, safety, and health; waste management; cost; technical maturity; and socioeconomics to assist in the evaluation of a Request for Recommendation submittal from Cogema.

Cogema operates the only production-scale plant in the world for converting depleted $UF_6$ to $U_3O_8$. Located at the Tricastin site in the Rhone Valley in France, this plant, which began operation in 1984, converts 20,000 metric tons (MT) of depleted $UF_6$ into $U_3O_8$ per year. Currently, the $U_3O_8$ is packed and stored onsite in metallic containers which are suitable for long-term, retrievable storage. The plant also recovers aqueous HF acid from the conversion process. The aqueous HF, which is temporarily stored onsite in tanks, is sold to the European chemicals industry, where a ready market for this material exists (Cogema 1994a, 1994b, 1989). In North America, however, the market for aqueous HF is limited.

### 1.1 Process Description

The generic process for converting of depleted $UF_6$ to $U_3O_8$ utilizes a two-step reaction: (1) hydrolysis of depleted $UF_6$ and (2) conversion of uranyl fluoride ($UO_2F_2$) to $U_3O_8$. The reaction stoichiometry is summarized below:

(1) $UF_6 + 2\ H_2O \dashrightarrow UO_2F_2 + 4\ HF$

(2) $3\ UO_2F_2 + 2\ H_2O + H_2 \dashrightarrow U_3O_8 + 6\ HF$

In the presence of steam (at 250°C), depleted $UF_6$ is hydrolyzed to $UO_2F_2$ by an exothermic reaction. When pyrohydrolyzed at a high temperature (about 750°C), the uranyl fluoride is decomposed to $U_3O_8$ by a slow and reversible endothermic reaction (Cogema 1994b).

The conversion process starts with the vaporization of solid depleted $UF_6$ in an autoclave. Gaseous $UF_6$ is then fed to the reactor section of a conversion furnace, where it is heated to 250°C in the presence of nitrogen ($N_2$) and steam. In the reactor section, the $UF_6$ releases heat and yields two reaction products, solid $UO_2F_2$ and gaseous HF. The solid $UO_2F_2$ is transferred by a screw feeder to the second reactor section, consisting of a rotary furnace that is heated externally by electrical elements. In the furnace, the $UO_2F_2$ combines with hydrogen ($H_2$) and

equilibrium is shifted to favor formation of $U_3O_8$ with a large excess of steam. The $U_3O_8$ is sent through a three-valve chamber to a compacting installation to increase its bulk specific gravity from 1.3 to 3, which significantly reduces its storage volume. The $U_3O_8$ is transferred by a conveyor system and loaded into containers for storage and ultimate disposal. The gases leaving the furnace (HF, $H_2O$, and $N_2$) are passed through cartridge filters to remove any traces of uranium solids. These gases are then condensed, and the aqueous HF solution (containing 70% by weight) is recovered and stored in bulk for sale. The remaining gaseous mixture is scrubbed in a countercurrent flow of water, then released to the atmosphere (Cogema 1994b, 1989).

HF Recovery

Cogema recovers and recycles the fluorine content of the $UF_6$ as 70% HF in aqueous solution. This is a high purity product with a ready market in the European chemicals industry (Cogema 1989).

## 1.2 Input Materials

The primary input materials for the depleted $UF_6$ conversion process are depleted $UF_6$, $H_2O$, and $H_2$. The annual quantities required for each material are presented in Table 1. The operating capacity of the Cogema plant is 20,000 MT (as depleted $UF_6$) per year. An operating capacity of 28,000 MT per year would be required to process the 560,00 MT inventory of depleted $UF_6$.

***Table 1. Annual Input Quantities for the Defluorination Process***

| Input Materials | Current Cogema Operating Capacity | Capacity Requirements for 20-Year Inventory Conversion |
|---|---|---|
| Depleted $UF_6$ | 20,000 MT/yr[a] | 28,000 MT/yr |
| $H_2O$ | 6,000 - 10,000 MT/yr (est.) | 8,400 - 14,000 MT/yr (est). |
| $H_2$ | 100 - 200 MT/yr (est.) | 140 - 280 MT/yr (est). |

[a]Cogema 1994b.
est. = estimate

## 1.3 Products

The primary products from the depleted $UF_6$ conversion process are $U_3O_8$ and aqueous HF. The annual quantities of each product are presented in Table 2.

***Table 2. Annual Product Quantities from the Defluorination Process***

| Product Materials | Quantity | Potential Applications/Uses |
|---|---|---|
| $U_3O_8$ | 16,000 MT/yr[a]<br>22,400 MT/yr[b] | - Disposal (Package A1)<br>- Ducrete (Package B1)<br>- Storage (Package C1) |
| Aqueous HF (70%) | 10,000 MT/yr[a]<br>14,000 MT/yr[b] | - Sold as product (in Europe) |

[a]Based on 20,000 MT per year of $UF_6$ processed (Cogema 1994b).
[b]Based on 28,000 MT per year of $UF_6$ processed.

## 1.4 Depleted $UF_6$ Consumption

As shown in Table 2, the current nominal capacity of the Cogema conversion plant is 16,000 MT/year $U_3O_8$ (Cogema 1994a, 1994b). To convert the entire DOE inventory of depleted $UF_6$ to $U_3O_8$ in 20 years would require an annual capacity of 28,000 MT.

## *EVALUATION FACTORS*

## A. ENVIRONMENT, SAFETY, AND HEALTH

The construction and operation of a depleted $UF_6$ conversion plant in the United States would be regulated by 10 CFR Part 40, *Domestic Licensing of Source Material.* Environment, safety, and health issues would be covered by these and other federal, state, and local regulations.

### A.1 Operations, Handling, Storage, Transportation, and Disposal

Materials that would be used in the domestic production of $U_3O_8$ and aqueous HF at depleted uranium conversion facilities are covered by federal, state, and local regulations pertaining to process safety, transportation, handling, storage, and disposal.

In 1977, French officials determined that storage of depleted $UF_6$ from enrichment operations should be limited in time and quantity. License conditions were established for the enrichment facilities, which resulted in Cogema implementing a project for converting the depleted $UF_6$ inventory to $U_3O_8$ on an industrial scale. Currently, Cogema packs and stores the $U_3O_8$ in 3-cubic-meter metal containers. Each container has a capacity of 9 tons. The containers are placed on concrete pads and are housed in metal framed, seismic resistant modular sheds. Each shed can hold 2,600 containers. With 12 sheds located onsite, Cogema estimates a $U_3O_8$ storage capacity of roughly 20 years (Cogema 1989).

Nuclear Regulatory Commission (NRC) regulations (10 CFR 20.1301) require that the total effective dose equivalent for releases related to routine operations (i.e., for a generic depleted $UF_6$ conversion plant) should not exceed 1 milliSievert (mSv) per year. In addition, Environmental Protection Agency (EPA) regulations (40 CFR Part 190) require that for routine releases to the general environment, the annual dose equivalent should not exceed 0.25 mSv to the whole body, 0.75 mSv to the thyroid, and 0.25 mSv to any other organ. For releases to the atmosphere, EPA regulations (40 CFR Part 61) require that the annual effective dose equivalent should not exceed 0.1 mSv. Based on an assessment of the environmental impacts of depleted $UF_6$ disposition, the NRC concluded[1] that for radiological exposure,

> ...operation of the $DUF_6$ conversion plant is expected to have negligible radiological impacts on the environment. (NRC 1994)

[1]Appendix A of NUREG-1484, *Claiborne Enrichment Center Environmental Impact Statement*, assessed the environmental impacts from conversion and long-term disposal of $U_3O_8$ produced by the proposed Louisiana Energy System enrichment plant.

Transportation

Transportation of hazardous materials, including $UF_6$ and HF, would be conducted according to Title 49 CFR.

Disposal

Disposal of $U_3O_8$ is described in Information Package A1. In general, based on assumptions regarding $U_3O_8$ disposal by emplacement in near-surface or deep geological environments, the NRC concluded that,

> It should be noted that the estimated doses [from a near-surface disposal facility] are significantly above the limits specified in 10 CFR Part 61,... Because for near-surface disposal of $U_3O_8$, projected doses exceed 10 CFR Part 61 limits, a deep disposal site is most likely to be selected for ultimate disposition of depleted uranium. (NRC 1994).

The NRC analysis assumed a wet, eastern, near-surface disposal facility. Near-surface disposal may be a viable option if an arid disposal site remote from population centers is used, or actual waste form performance is considered. These considerations were not included in the CEC EIS (SAIC 1994).

## A.2 Siting Factors

Siting standards for depleted $UF_6$ conversion plants are covered in NRC licensing regulations for the possession and use of source material. According to 10 CFR Part 40.31, to obtain a license to possess and use source material, such as depleted uranium, an application must be filed with the NRC at least 9 months prior to the start of construction, accompanied by any Environmental Report required pursuant to 10 CFR Part 51. The Environmental Report must describe the environmental impacts of the construction, operation, and decommissioning of the plant and include the status of compliance with all applicable federal, state, regional, and local regulations for environmental protection, including zoning and other land-use restrictions. Under 10 CFR Part 40, the license application for possessing and using source material must provide installation information pursuant to 10 CFR Part 75.11, which, for siting, includes identifying the geographic location of the plant.

Land requirements for a depleted $UF_6$ conversion plant are unknown at this time. The Cogema plant is part of a larger complex at Tricastin which includes four light water reactors and the Georges Besse enrichment facility. The Tricastin site occupies an area comparable to

that for the gaseous diffusion plant at Paducah, Kentucky (approximately 2.6 $km^2$). For comparison purposes, the NRC assumed that a 4,550 MT/yr generic depleted $UF_6$ conversion plant would occupy a 4 $km^2$ site (NRC 1994).

### A.3 Public and Worker Safety

Uranium hexafluoride is a volatile substance that forms hydrofluoric acid and $UO_2F_2$ when exposed to moisture in ambient air. Both products are soluble in water and pose a significant health hazard. The uranium in the uranyl fluoride acts as a heavy metal poison that can affect the kidneys. The hydrofluoric acid can burn the skin and the lungs. Exposure to any fluoride can also cause fluoride poisoning. The chemical toxicity of the uranium, rather than the radiation dose, is the limiting factor when considering exposure effects.

According to a study by Martin Marietta,

> $U_3O_8$ is one of the most inert chemical forms of uranium, can be stored safely, and has the lowest potential impact on people and the environment in the event storage or disposal facilities are abandoned in the future. Major advantages of $U_3O_8$ are the relatively low chemical reactivity, solubility, and risks compared to alternate uranium forms. $U_3O_8$ is insoluble even in weak acids and bases typically found in soils and groundwater. (Martin Marietta 1990).

Public and worker safety would be addressed by the material license for operating a depleted $UF_6$ conversion plant. In addition, some of the unit operations are similar to those at commercial nuclear fuel fabrication plants.

## B. WASTE MANAGEMENT

### B.1 Waste Storage, Transportation, Treatment, or Disposal

At Cogema, the depleted uranium conversion facility produces no liquid effluents. Gases leaving the rotary furnace are filtered by cartridge filters to remove any traces of solids ($UO_2F_2$ and/or $U_3O_8$), which are then separated in a series of porous metal filters. The particulate/gas separation efficiency of each filter is on the order of 99.9%. After the gases are cooled, they are routed to the HF scrubbers. Non-condensable gases released to the atmosphere contain less than 3 parts per million (ppm) of HF. All the fluorine in the depleted $UF_6$ is converted to hydrofluoric acid. The aqueous HF is temporarily stored onsite in 20-$m^3$ tanks before being transferred to rail cars or other transport vehicles for delivery to the European chemicals industry (Cogema 1989).

There do not appear to be any unique waste management concerns with operation of a depleted $UF_6$ conversion plant. The HF acid and $UO_2F_2$ which are formed when $UF_6$ is exposed to moisture in ambient air are hazardous wastes listed under the Resource Conservation and Recovery Act (RCRA). The NRC concluded that, based on 10 CFR Part 61 limits, a deep disposal site is most likely to be selected for ultimate disposition of depleted $U_3O_8$ (NRC 1994). However, the NRC analysis assumed a wet, eastern, near-surface disposal facility. Near-surface disposal may be a viable option if an arid disposal site remote from population centers is used, or actual waste form performance is considered. These considerations were not included in the CEC EIS (SAIC 1994).

### B.2 Recycling Potential

The very low uranium concentration in the aqueous HF product allows for its possible sale. The $U_3O_8$ product could be

(1) disposed of as is (see Package A1),
(2) used in the production of Ducrete (see Package B1), or
(3) placed in long-term, retrievable storage (see Package C1).

## C. COSTS

### C.1 Capital Costs, Annual Operations and Maintenance Costs

Capital and operating costs for a depleted $UF_6$ conversion plant are unknown at this time. Cogema quoted a conversion cost of $3.00/kg U as $UF_6$, assuming recovery and credit for the sale of aqueous HF (Cogema 1994b).

### C.2 Product Value/Facility Salvage

At Cogema, recovered aqueous HF is returned to the commercial market through an industrial sales arrangement. This HF accounts for about 30% of the aqueous HF consumed in Europe on an annual basis (Cogema 1994a). In North America, however, the market for aqueous HF is limited.

C.3 Cost Avoidance through By-Product Sales

As indicated earlier, Cogema quotes a conversion cost of $3.00/kg U as $UF_6$, which includes recovery and credit for the sale of aqueous HF (Cogema, 1994b). No other by-product sales data are available at this time.

## D. TECHNICAL MATURITY

The depleted $UF_6$ conversion process is a standard industrial practice, with a commercial plant in operation. As such, the technology is considered mature and would probably not require any new design work. In addition, several domestic plants involved in the commercial nuclear fuel cycle utilize similar technologies to convert enriched $UF_6$ into $UO_2$, so a technology base already exists here in the United States.

## E. SOCIOECONOMICS

E.1 Employment

Actual employment data for a depleted $UF_6$ conversion plant are not available at this time.

E.2 Public Acceptance

No formal evaluation of public acceptance has been made at this time. Some limited public resistance to the siting and licensing of a depleted $UF_6$ conversion plant could be expected. However, its low environmental impacts, together with employment opportunities, would be expected to result in strong competition among potential host communities.

E.3 Local/Regional Development

Local and regional development resulting from the construction and operation of a depleted $UF_6$ conversion plant cannot be measured at this time.

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# INFORMATION PACKAGE 2

# Defluorination Producing $U_3O_8$ and an Anhydrous HF By-Product

This Information Package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on Depleted $UF_6$ technologies or applications currently under consideration by the Department of Energy. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; it is intended to provide sufficient information to assist the Independent Technical Reviewer.

# *DEFLUORINATION PRODUCING $U_3O_8$ AND AN ANHYDROUS HF BY-PRODUCT*

## 1. OVERVIEW

This information package briefly describes the conversion of depleted uranium hexafluoride ($UF_6$) to triuranium octaoxide ($U_3O_8$) using a defluorination process that produces an anhydrous hydrogen fluoride (AHF) by-product. It also provides supplemental data on environment, safety, and health; waste management; cost; technical maturity; and socioeconomics to assist in the evaluation of Request for Recommendation submittals from General Atomics and Cameco.

No production-scale plant exists for converting depleted $UF_6$ into $U_3O_8$ and producing by-product AHF. However, the General Atomics process described here is similar to the existing industrial depleted $UF_6$ conversion process used by Cogema (Cogema 1994a). The primary difference between these two processes is the production of aqueous HF by Cogema compared to the production of AHF by this process. The aqueous HF by-product from the Cogema defluorination process is sold to the European chemical industry. In North America, the market for aqueous HF is limited; however, a significant market exists for AHF.

### 1.1 Process Descriptions

Anhydrous HF can be produced by defluorination using distillation and thermal decomposition techniques. The General Atomics distillation process is based on U.S. Patent #5,346,684. Cameco uses thermal decomposition and has sought patent rights in the United States and Canada for this process. Both processes are described below.

#### General Atomics

The overall reaction for the conversion of depleted $UF_6$ to $U_3O_8$ and recovery of AHF is as follows:

$$(1) \quad 3\ UF_6 + 9\ H_2O \rightarrow U_3O_8 + 18\ HF + \tfrac{1}{2}\ O_2$$

As shown in Figure 1, the conversion process starts with the vaporization of solid depleted $UF_6$ in an autoclave. The gaseous $UF_6$ is fed to a primary reactor where it is combined with a gaseous azeotrope ($2\ H_2O \cdot HF$) and heated to 300°C in excess air to produce uranyl fluoride ($UO_2F_2$) and a gaseous mixture of HF and water. The $UO_2F_2$ is fed to a secondary reactor and reacted with superheated steam at 500°C to produce $U_3O_8$ and a gaseous mixture of HF, $H_2O$, and $O_2$. The product $U_3O_8$ is transferred from the secondary reactor for loading

into storage containers. The two mixtures from the primary and secondary reactors are combined and subsequently separated in a distillation column to obtain an AHF product stream and an aqueous azeotrope (2 $H_2O$•HF) recycle stream, which is vaporized and returned to the primary reactor as the steam feed (General Atomics 1994).

Cameco

Cameco proposed two processes for converting $UF_6$ to $U_3O_8$ . One process is similar to that proposed by General Atomics (see previous section).

The other Cameco process utilizes a two-step reaction: (1) defluorination of depleted $UF_6$ and (2) thermal decomposition of uranyl sulfate ($UO_2SO_4$) to $U_3O_8$. The reaction stoichiometry is summarized below:

(1) $UF_6 + 2\ H_2O + H_2SO_4 \dashrightarrow UO_2SO_4 + 6\ HF$

(2) $3\ UO_2SO_4 \dashrightarrow U_3O_8 + 3\ SO_3 + \frac{1}{2}\ O_2$

As shown in Figure 2, this process is based on the reaction of $UF_6$ with aqueous $H_2SO_4$ of a suitable concentration to yield AHF and an insoluble $UO_2SO_4$ complex in an acidic aqueous solution containing $UO_2SO_4$ and HF. While the gaseous AHF is easily removed from the reaction vessel and recovered from a cold trap as liquid AHF, the acid aqueous solution is transferred to a drying process and subsequently subjected to a thermal decomposition process yielding $U_3O_8$ and an off-gas. The $H_2SO_4$ used in defluorination is partially recovered and recycled to the defluorination stage. AHF generated in the defluorination stage would be recovered in cold traps as liquid AHF. Small amounts of HF, transferred with the $UO_2SO_4$ intermediate, would be recovered with the liquid phase recycled from both the liquid/solid separation and the $H_2SO_4$ generated from the off-gas of the thermal decomposition stage. The acid recovery system would be a combination of ordinary absorption units and a modified tower process to avoid use of catalysts and potential fouling problems caused by fluorides (Cameco 1995).

AHF Recovery

Both processes recover the fluorine content of the $UF_6$ as AHF. This product has a ready market in North America.

*Figure 1. General Atomics Defluorination Process*

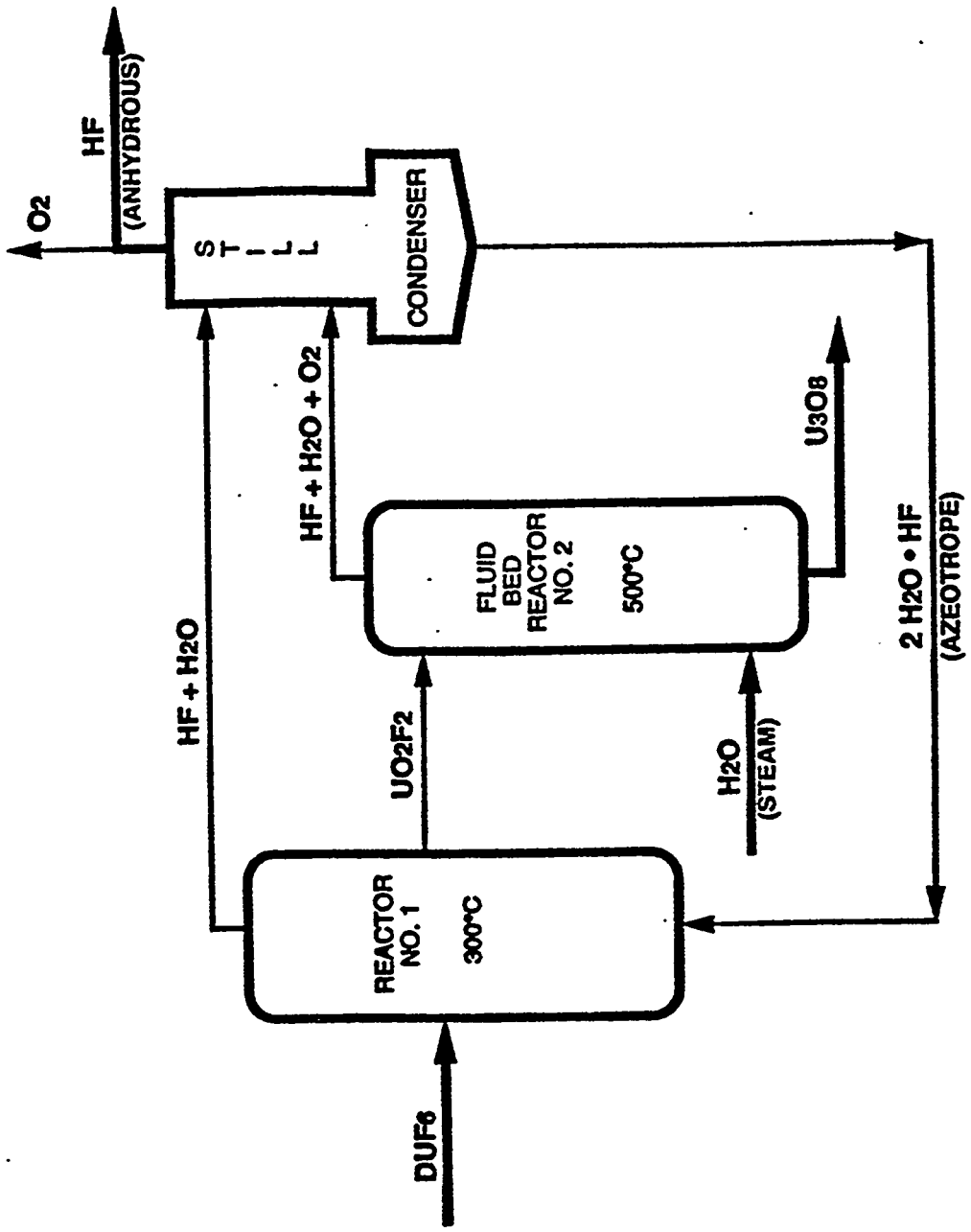
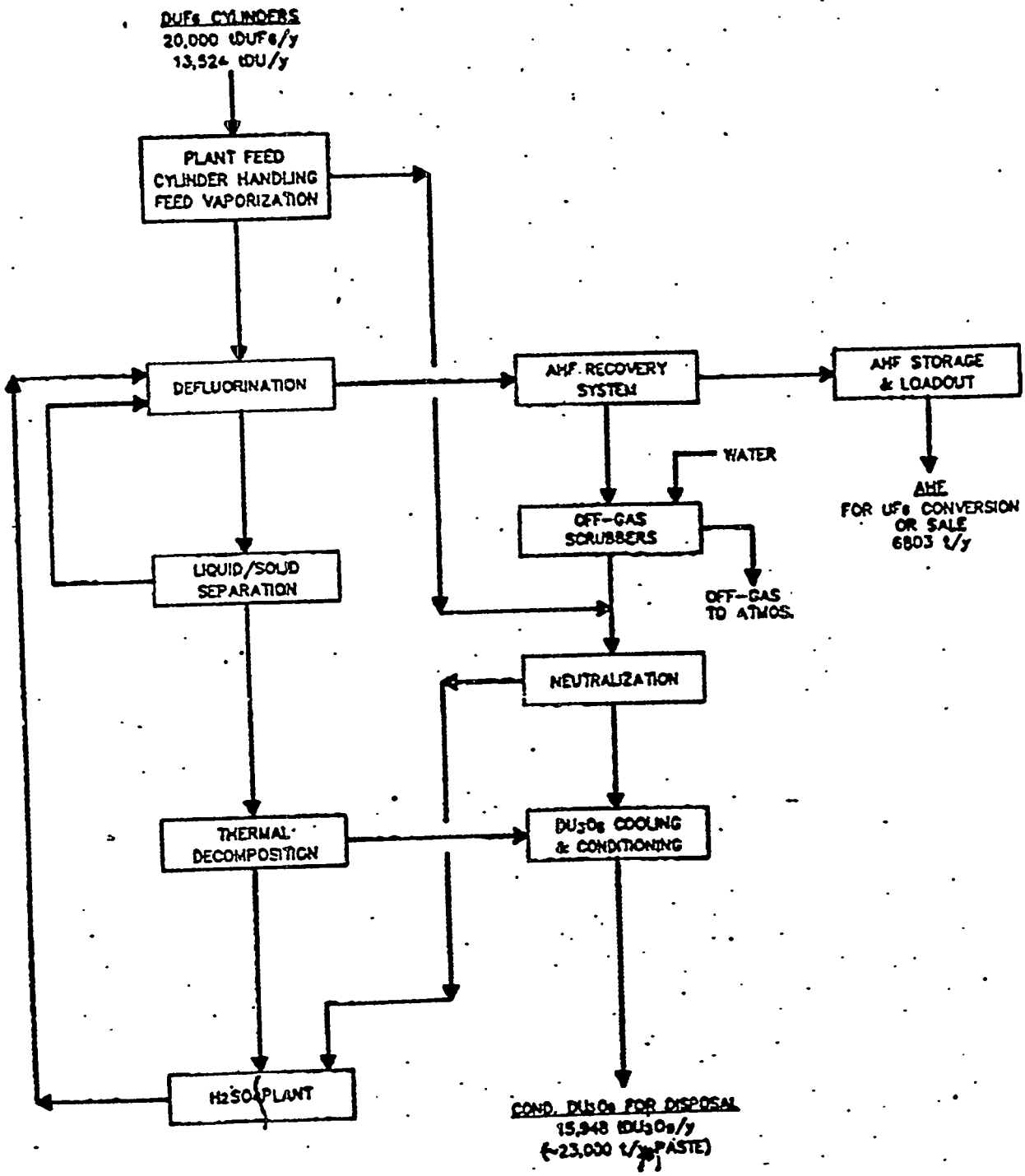


*Figure 2. Cameco Defluorination Process*



## 1.2 Input Materials

The primary input material for these processes is depleted $UF_6$. Estimated plant capacities for the General Atomics and Cameco conversion processes are 37,300 MT/yr and 20,000 MT/yr (as depleted $UF_6$), respectively (General Atomics 1994, Cameco 1995).

## 1.3 Products

The primary products from these processes are $U_3O_8$ and AHF. The annual quantities for each material are shown in Table 1. The General Atomics output quantities are based on an input rate of 37,300 MT/yr (as depleted $UF_6$), while the Cameco output quantities are based on 20,000 MT/yr input.

*Table 1. Annual Product Quantities from the Defluorination Processes*

| Product Materials | Estimated Operating Capacity | Potential Applications/Uses |
|---|---|---|
| $U_3O_8$<br>- General Atomics<br>- Cameco | 29,770 MT/yr[a]<br>15,950 MT/yr[b] | - Disposal (Package A1)<br>- Ducrete (Package B1)<br>- Storage (Package C1) |
| Anhydrous HF<br>- General Atomics<br>- Cameco | 12,700 MT/yr[a]<br>6,800 MT/yr[b] | - Sold as product |

[a](General Atomics 1994).
[b](Cameco 1995).

## 1.4 Depleted $UF_6$ Consumption

For either process, to convert the entire DOE inventory of depleted $UF_6$ in 20 years to $U_3O_8$ would require an annual capacity of 28,000 MT.

## *EVALUATION FACTORS*

## A. ENVIRONMENT, SAFETY, AND HEALTH

The construction and operation of a depleted $UF_6$ conversion plant in the United States would be regulated by 10 CFR Part 40, *Domestic Licensing of Source Material.* Environment, safety, and health issues would be covered by these and other federal, state, and local regulations.

### A.1 Operations, Handling, Storage, Transportation, and Disposal

Materials that would be used in the domestic production of $U_3O_8$ and AHF at a depleted uranium conversion facility are covered by federal, state, and local regulations pertaining to process safety, transportation, handling, storage, and disposal.

Nuclear Regulatory Commission (NRC) regulations (10 CFR 20.1301) require that the total effective dose equivalent for releases related to routine operations (i.e., for a generic depleted $UF_6$ conversion plant) should not exceed 1 milliSievert (mSv) per year. In addition, Environmental Protection Agency (EPA) regulations (40 CFR Part 190) require that for routine releases to the general environment, the annual dose equivalent should not exceed 0.25 mSv to the whole body, 0.75 mSv to the thyroid, and 0.25 mSv to any other organ. For releases to the atmosphere, EPA regulations (40 CFR Part 61) require that the annual effective dose equivalent should not exceed 0.1 mSv. Based on an assessment of the environmental impacts of depleted $UF_6$ disposition, the NRC concluded[1] that for radiological exposure,

> ...operation of the $DUF_6$ conversion plant is expected to have negligible radiological impacts on the environment. (NRC 1994)

No significant problems are anticipated, since existing environmental, health, and safety permits are in place for handling $UF_6$, $U_3O_8$, and AHF at domestic facilities, such as the AlliedSignal Metropolis Works plant in Metropolis, Illinois (General Atomics 1994).

[1]Appendix A of NUREG-1484, *Claiborne Enrichment Center Environmental Impact Statement*, assessed the environmental impacts of conversion and long-term disposal of the $U_3O_8$ produced by the proposed Louisiana Energy System enrichment plant.

Transportation

Transportation of hazardous materials, including $UF_6$ and HF, would be conducted according to Title 49 CFR.

Disposal

Disposal of $U_3O_8$ is described in Information Package A1. In general, based on assumptions regarding $U_3O_8$ disposal by emplacement in near-surface or deep geological environments, the NRC concluded that,

> It should be noted that the estimated doses [from a near-surface disposal facility] are significantly above the limits specified in 10 CFR Part 61,.... Because for near-surface disposal of $U_3O_8$, projected doses exceed 10 CFR Part 61 limits, a deep disposal site is most likely to be selected for ultimate disposition of depleted uranium. (NRC 1994).

The NRC analysis assumed a wet, eastern, near-surface disposal facility. Near-surface disposal may be a viable option if an arid disposal site remote from population centers is used, or actual waste form performance is considered. These considerations were not included in the CEC EIS (SAIC 1994).

## A.2 Siting Factors

Siting standards for depleted $UF_6$ conversion plants are covered in NRC licensing regulations for the possession and use of source material. According to 10 CFR Part 40.31, to obtain a license to possess and use source material, such as depleted uranium, the application must be filed with the NRC at least 9 months prior to the start of construction, accompanied by any Environmental Report required pursuant to 10 CFR Part 51. The Environmental Report must describe the environmental impacts of the construction, operation, and decommissioning of the plant and include the status of compliance with all applicable federal, state, regional, and local regulations for environmental protection, including zoning and other land-use restrictions. Under 10 CFR Part 40, the license application for possessing and using source material must provide installation information pursuant to 10 CFR Part 75.11, which, for siting, includes identifying the geographic location of the plant.

Land requirements for a depleted $UF_6$ conversion plant are not clearly defined at this time. As an approximation, the NRC assumed that a 4,550 MT/yr generic depleted $UF_6$ conversion plant would occupy a 4-$km^2$ site (NRC 1994). A depleted $UF_6$ conversion plant for 28,000 MT/yr capacity would require a larger site.

A.3 Public and Worker Safety

Uranium hexafluoride is a volatile substance that forms hydrofluoric acid and $UO_2F_2$ when exposed to moisture in ambient air. Both products are soluble in water and pose a significant health hazard. The uranium in the uranyl fluoride acts as a heavy metal poison that can affect the kidneys. The hydrofluoric acid can burn the skin and the lungs. Exposure to any fluoride can also cause fluoride poisoning. The chemical toxicity of the uranium, rather than the radiation dose, is the limiting factor when considering exposure effects.

According to a study by Martin Marietta,

> $U_3O_8$ is one of the most inert chemical forms of uranium, can be stored safely, and has the lowest potential impact on people and the environment in the event storage or disposal facilities are abandoned in the future. Major advantages of $U_3O_8$ are the relatively low chemical reactivity, solubility, and risks compared to alternate uranium forms. $U_3O_8$ is insoluble even in weak acids and bases typically found in soils and groundwater. (Martin Marietta 1990).

Public and worker safety would be addressed by the material license for operating a depleted $UF_6$ conversion plant. In addition, some of the unit operations are similar to those at commercial nuclear fuel fabrication plants.

## B. WASTE MANAGEMENT

B.1 Waste Storage, Transportation, Treatment, or Disposal

There do not appear to be any unique waste management concerns with the operation of a depleted $UF_6$ conversion plant. The hydrofluoric acid and $UO_2F_2$ which are formed when $UF_6$ is exposed to moisture in ambient air are hazardous wastes according to the Resource Conservation and Recovery Act (RCRA). The General Atomics process does not produce secondary waste streams requiring treatment and disposal (General Atomics 1994). According to Cameco, its process will produce small amounts of uranium precipitates and calcium fluoride, including water insoluble daughter products obtained from cylinder washing, which would end up as conditioned $U_3O_8$ paste product (Cameco 1995).

The NRC concluded that, based on 10 CFR Part 61 limits, a deep disposal site is most likely to be selected for ultimate disposition of depleted $U_3O_8$ (NRC 1994). However, the NRC analysis only assumed a wet, eastern, near-surface disposal facility. The NRC analysis assumed a wet, eastern, near-surface disposal facility. Near-surface disposal may be a viable option if an arid disposal site remote from population centers is used, or actual waste form

performance is considered. These considerations were not included in the CEC EIS (SAIC 1994).

### B.2 Recycling Potential

Based on Cogema's experience of very low uranium concentration levels in its aqueous HF by-product, both General Atomics and Cameco expect their processes to also yield very low uranium concentrations in the AHF by-product (General Atomics 1994, Cameco 1995). Very low uranium concentrations would allow for the sale of AHF. The $U_3O_8$ product could be

(1) disposed of as is (see Package A1),
(2) used in the production of Ducrete (see Package B1), or
(3) placed in long-term, retrievable storage (see Package C1).

## C. COSTS

### C.1 Capital Costs, Annual Operations and Maintenance Costs

General Atomics estimates that demonstrating the conversion process and the transportation and storage or disposal of $U_3O_8$ would cost between $20 and $50 million. Further, construction of a production-scale plant to process the DOE inventory in 15 to 20 years would cost an additional $80 to $100 million (General Atomics 1994).

General Atomics also estimates that the price for converting and preparing for storage or disposing of depleted $UF_6$ would be in the range of $2.20/kg U, as $UF_6$. This price includes conversion operations, transportation, facility depreciation, and decontamination and decommissioning (General Atomics 1994).

Cameco estimates a capital cost of $280 million, including technology development, equipment, siting and licensing, and contingency costs (Cameco 1995).

### C.2 Product Value/Facility Salvage

The recovered AHF would be sold to the commercial market through an industrial sales arrangement.

### C.3 Cost Avoidance through By-Product Sales

The estimated value of AHF produced would be in the range of $500 to $1,000 per ton (General Atomics 1994).

## D. TECHNICAL MATURITY

Conceptually, the process, equipment, and plant operations for conversion of depleted $UF_6$ to $U_3O_8$ are very similar to those used for the production of $UF_6$. However, no production-scale plants exist that convert depleted $UF_6$ into $U_3O_8$ and produce the by-product AHF.

General Atomics has completed research and development of the patented process. Laboratory results have confirmed the chemical reactions, indicated the purity of the AHF and $U_3O_8$ produced, and demonstrated that the physical characteristics of $UO_2F_2$ and $U_3O_8$ are well suited to conventional material handling. Test results have provided confidence that commercial-scale processing can be performed reliability and cost-effectively. General Atomics states that construction and operation of a demonstration plant is required to provide design, operating, reliability, and financial information for planning production-scale operations. Chemical purity and acceptance of the AHF product for commercial applications would be demonstrated, and complete fluorine removal from the $U_3O_8$ would be confirmed. General Atomics proposes to use the AlliedSignal Metropolis Works in Metropolis, Illinois, to demonstrate the process. In addition, a significant portion of the equipment for a demonstration program is available from the Sequoyah Fuels Corporation plant at Gore, Oklahoma. The balance of required equipment is either commercially available or would be based on equipment currently in use for $UF_6$ production or AHF processing. Testing and demonstration could be completed within 2 to 3 years (General Atomics 1994).

Cameco's thermal decomposition process uses start-of-the-art technology from the chemical industry. Research and development work in the areas of process optimization and product purity for AHF and $U_3O_8$ has been performed in a bench-scale test program. Further demonstration work is required for selected equipment, mainly for the liquid/solid separation and calcination stages. Testing and demonstration could be completed within 18 to 24 months (Cameco 1995).

## E. SOCIOECONOMICS

### E.1 Employment

Cameco estimated a labor requirement of 160 for operations only (Cameco 1995).

### E.2 Public Acceptance

No formal evaluation of public acceptance has been made at this time. Some limited public resistance to the siting and licensing of a new depleted $UF_6$ conversion plant could be expected.

## E.3 Local/Regional Development

Local and regional development resulting from construction and operation of a depleted $UF_6$ conversion plant cannot be measured at this time.

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[2]Request for Recommendation #21.

[3]Request for Recommendation #6.

[4]Request for Recommendation #5.

# INFORMATION PACKAGE 3

# Improved AMES Process

This Information Package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on Depleted $UF_6$ technologies or applications currently under consideration by the Department of Energy. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; it is intended to provide sufficient information to assist the Independent Technical Reviewer.

# IMPROVED AMES PROCESS

## 1. OVERVIEW

The Ames process has been the standard industrial method for the production of uranium metal for over 50 years (Benedict et al.). The feedstock is uranium tetrafluoride ($UF_4$), produced by the reduction of uranium hexafluoride ($UF_6$) with hydrogen ($H_2$) in a continuous process.

$$UF_6 + H_2 \longrightarrow UF_4 + 2HF$$

The uranium metal is produced in a batch process by metallothermic reduction of $UF_4$ by magnesium metal (Mg).

$$UF_4 + 2Mg \longrightarrow U + 2MgF_2$$

The magnesium fluoride ($MgF_2$) by-product slag contains appreciable quantities of uranium (typically, 4- 8 wt. %) in various possible forms, including metal, fluorides, oxides, and oxyfluoride compounds. At these uranium levels, the $MgF_2$ cannot be used for other applications, and it must be disposed of in a low-level-waste (LLW) burial site. For each kilogram of uranium metal produced, $10^2$ cubic feet of contaminated $MgF_2$ is generated. With the rising costs for LLW disposal, the disposal cost is becoming a significant fraction of the production cost. Apart from financial considerations, new facilities in the future may be required to minimize waste volumes.

The primary improvement to the Ames process is the decontamination of the $MgF_2$ slag to a level at which it can be disposed of as a non-LLW. Based on an exemption level of 35 picocuries/gram, the depleted uranium content must be reduced to less than approximately 100 ppm for disposal in a sanitary landfill. Leaching has been used for separating uranium from $MgF_2$. However, in most cases, the primary objective has been uranium recovery and not slag decontamination.

This information package may be useful when evaluating the response to the Request for Recommendations from Cameco (RFR #21).

### 1.1 Generic Process Description

Metal-grade $UF_4$ from the reduction of $UF_6$ in a tower reactor is mixed with a slight excess of magnesium metal and placed in a $MgF_2$-lined sealed reactor vessel, designed to contain the super atmospheric pressure of Mg when the reactants are elevated to the melting point of $MgF_2$. The vessel is preheated and the reaction is initiated at about 600 C. Once initiated, the exothermic reaction is

The higher density uranium metal collects at the bottom of the reactor, and the lower density $MgF_2$ accumulates on the top. After extended cooling, the uranium "derby" is separated from the $MgF_2$ slag. After breakout, the slag is ground and screened, and metal "pellets" are recovered. The ground $MgF_2$ slag, containing residual uranium and magnesium, is nitric acid ($HNO_3$) leached ($MgF_2$ is relatively insoluble in nitric acid). A multi-stage $HNO_3$ countercurrent leach process is used. After leach, the decontaminated $MgF_2$ is dried and drummed for non-LLW disposal or possible sale. The nitric acid leach liquor, containing dissolved uranium, magnesium, and some $MgF_2$, is evaporated, calcined, and finally grouted with cement. The initial assumption is that it is not cost effective to recycle the uranium. The drummed grout is then stored for eventual disposal as LLW. There are many variations, including (1) alternate leaching reagents, (2) the inclusion of a roasting step prior to leaching, and (3) alternate immobilization routes.

Preliminary flow sheets have been prepared for the integrated process described above (LLNL 1995). The following summaries are based on an assumed annual metal demand of 10,000 tonnes.

## 1.1 Primary Material Inputs

The primary consumables are depleted $UF_6$, ammonia (hydrogen source), magnesium metal, nitric acid, and cement. The estimated annual quantities are presented in Table 1.

**Table 1. Annual Input Quantities**

| Input | Annual Quantity |
|---|---|
| Depleted $UF_6$ | 15,244 tonnes |
| Ammonia ($NH_3$) | 589 tonnes |
| Magnesium | 2,120 tonnes |
| Nitric acid (60%) | 105 tonnes |
| Cement | 975 tonnes |

## 1.2 Products

The products are uranium metal and anhydrous HF that is produced in the reduction of depleted $UF_6$ to $UF_4$. The annual quantities are presented in Table 2.

**Table 2. Annual Product Quantities**

| Product | Annual Quantity |
|---|---|
| Uranium metal | 10,000 tonnes (reference) |
| Anhydrous HF | 1,699 tonnes |

## 1.3 Solid Wastes

The principal solid wastes are the decontaminated $MgF_2$ (on the initial assumption it has no value) and the grouted uranium. The annual quantities are presented in Table 3.

**Table 3. Annual Solid Waste Quantities**

| Waste | Annual Quantity |
|---|---|
| $MgF_2$ (non-LLW) | 5,254 tonnes |
| Grout (LLW) | 2,166 tonnes |

## 1.4 Depleted $UF_6$ Consumption

The annual consumption of depleted $UF_6$ is 15,244 tonnes, based on an annual metal demand of 10,000 tonnes. At this rate, the depleted $UF_6$ stockpile would be consumed in about 40 years.

## 1.5 Alternate Processes

Several alternate pathways or combinations are possible to offset the cost for leaching and to reduce the amount of LLW. One such route would convert the $MgF_2$ with sulfuric acid to produce anhydrous HF for sale. (It should be noted that, unlike $CaF_2$, HF generation from $MgF_2$ is not a commercial process.) To reduce the quantity of LLW, the uranium could be removed from the leach liquor by precipitation (or other highly selective means) and the uranium recycled. The reader is referred to the Recommendation Response of Cameco Corporation (Cameco 1995). This proposes, along with other options, the sulfuric acid treatment of the contaminated slag to give anhydrous HF.

## A. ENVIRONMENT, SAFETY, AND HEALTH

The construction and operation of an integrated depleted uranium metal conversion plant in the United States would be regulated by 10 CFR Part 40, *Domestic Licensing of Source Materials*, which covers environmental, safety, and health issues. No evaluation of the ES&H issues has been made. However, the facility introduces no unique concerns; the materials and unit operations have been used in the uranium metal industry and commercial nuclear fuel cycle in general.

## B. WASTE MANAGEMENT

The two primary waste streams are (1) decontaminated $MgF_2$ (sanitary landfill disposal) and (2) grouted mixture of $U_3O_8/MgF_2/MgO$ (LLW disposal). The suitability of the grout as a LLW disposal form needs to be evaluated.

As previously indicated, there is the potential opportunity to use the $MgF_2$ beneficially and offset the cost of slag processing. In addition, the residual uranium could be recovered and recycled.

## C. COSTS

The costs for the integrated conversion plant (outlined above) have not been estimated. The recent price for uranium metal, starting with depleted $UF_6$ and including the waste costs, is judged to be roughly \$10/kg (EGG-MS-11297 and TDC-100, 1993). The production cost is sensitive to demand and the assumed LLW disposal fee.

## D. TECHNICAL MATURITY

The reduction of $UF_6$ to $UF_4$ and the metallothermic reduction of $UF_4$ to uranium metal are mature industrial technologies. Two domestic plants produce uranium metal from depleted $UF_4$ (Nuclear Metals Inc. [NMI] and Aerojet Ordnance Tennessee [AOT]). Their combined annual metal production capacity is roughly 7000 tonnes. One of these plants also converts $UF_6$ into $UF_4$.* Leaching has been extensively used, with the primary objective of recovering the uranium economic value from the natural and enriched uranium. However, one domestic uranium metal producer (AOT) is currently installing a leaching facility to decontaminate $MgF_2$ slag for disposal in a sanitary landfill. It is expected that the $MgF_2$ conversion to anhydrous HF will require some development and testing.

* Cameco (Canada) also has the capability to convert the hexafluoride to the tetrafluoride, as well as producing uranium metal.

# E. SOCIOECONOMICS

## E.1 Employment

This requires further evaluation. A rough order-of-magnitude estimate gives 300 personnel.

## E.2 Public Acceptance

The reduction of LLW volumes and recycling of materials, as compared to the current practice, would improve public acceptance.

## E.3 Local/Regional Development

Based on the estimated employment level, a significant economic benefit can be anticipated. No obvious technology spin-off opportunities are apparent.

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[1] RFR document #21

# INFORMATION PACKAGE
# 4

# Plasma Reduction of $UF_6$ to Metal

This Information Package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on Depleted $UF_6$ technologies or applications currently under consideration by the Department of Energy. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; it is intended to provide sufficient information to assist the Independent Technical Reviewer.

# PLASMA REDUCTION OF $UF_6$ TO METAL

## 1. OVERVIEW

High temperature plasma dissociation of uranium hexafluoride ($UF_6$) is an advanced concept for the production of uranium metal (U) and an anhydrous hydrogen fluoride (HF) by-product for sale. The overall reaction is

$$UF_6 + 3H_2 \longrightarrow U(metal) + 6HF$$

The initial kinetics involve the dissociation of $UF_6$ into its atomic constituents. Because the decomposition is very highly endoergic (~3000 kJ/mole), process temperatures of the order of 5000 K are required to ensure complete conversion.

The following information is derived from a preconceptual design study (draft) prepared for the Department of Energy by the Idaho National Engineering Laboratory (INEL 1994). The Los Alamos National Laboratory (LANL) is also investigating a plasma process for decomposition to the metal (LANL 1994). This process is described in a recommendation response (RFR #8) submitted by Manufacturing Sciences Corporation (MSC 1994). INEL recommended the plasma process in response to the Request for Recommendation (RFR#4). Both plasma processes are in the very early stages of development.

### 1.1 Process Description (INEL 1994)

Argon (Ar) gas is injected into a plasma torch, producing a > 10,000 K Ar plasma. A gaseous mixture of $UF_6$ and $H_2$ is introduced in the reactor section, downstream from the plasma torch. The complex ensuing chemistry involves the dissociation of $UF_6$ into its atomic constituents and, subsequently, the formation of submicron size uranium particles. Following reaction, the gas mixture is expanded and quenched to prevent the recombination of uranium and fluorine. After further cooling of the flowing stream, the submicron size uranium metal powder is separated from the gas mixture (HF, Ar, and excess $H_2$). The uranium metal powder is melted and cast into ingots. The HF is recovered from the gas mixture by cryogenic condensation and stored in tanks as a liquid. The $Ar/H_2$ mixture is separated using membrane technology, and the two components are recycled to the plasma torch and reactor, respectively. Figure 1 gives a functional diagram of the plasma reduction system.

The plant preconceptual design was sized for an annual feed rate of 20,000 tonnes $UF_6$. The plant contains 4 plasma reactor systems, each operating 5000 hours/year, or 1 tonne $UF_6$/reactor/h.

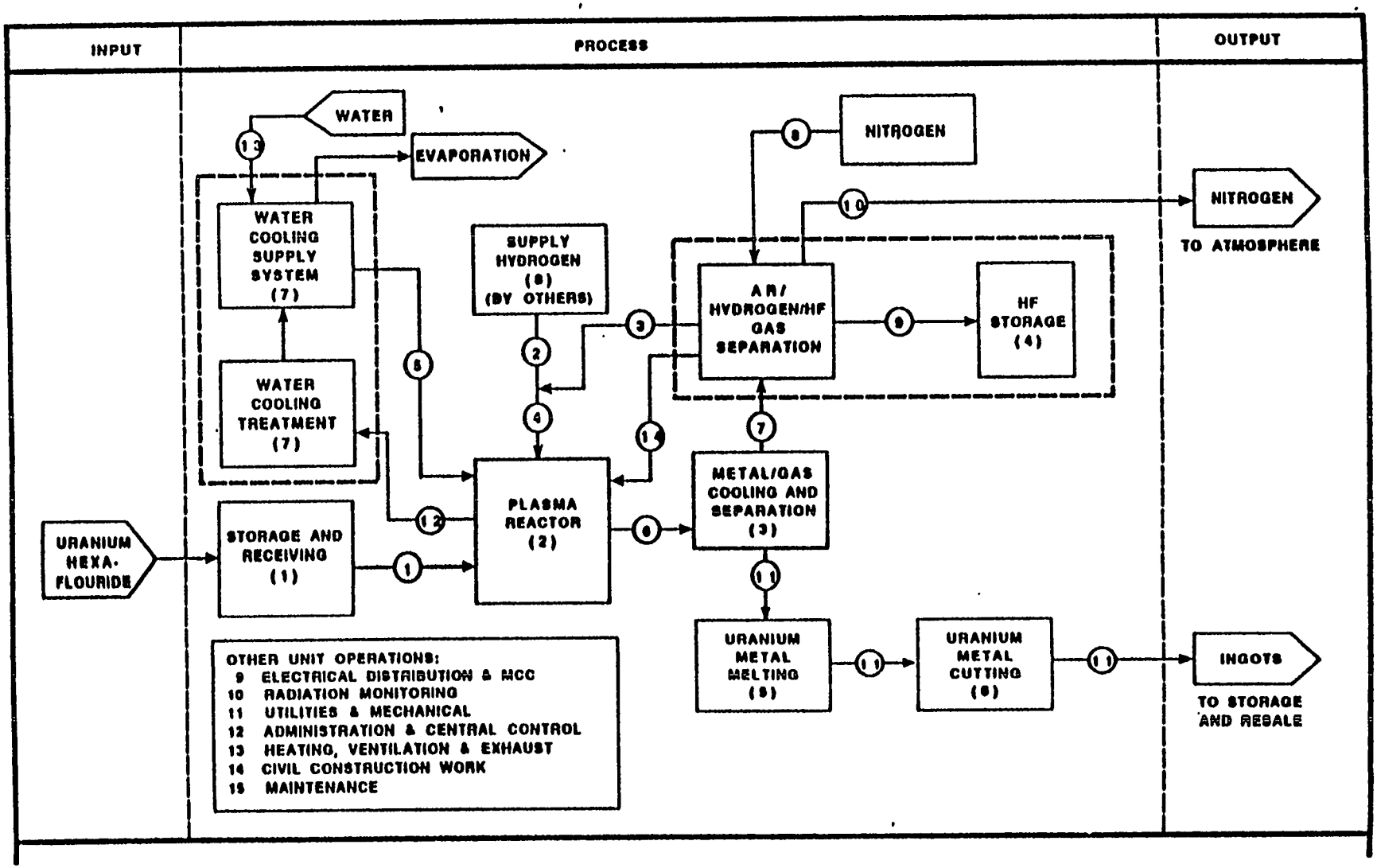


FIGURE 1. PLASMA PROCESS-FUNCTIONAL DIAGRAM

## 1.2 Primary Inputs

The major consumables include $UF_6$, $H_2$, and electrical energy. The annual quantities are presented in Table 1.

**Table 1. Annual Input Quantities**

| Input | Annual Quantity |
|---|---|
| Depleted $UF_6$ | 20,000 tonnes |
| $H_2$ | 196,500,000 SCF |
| Electricity | 250,000,000 kWH* |

SCF = standard cubic feet
$H_2$ generated from the dissociation of ammonia
kWH = kilowatt hours; value equivalent to 50 megawatts power for 5000 h
* Assuming ~ 3000kJ/mole for decomposition, power consumption is high relative to theoretical values.

## 1.3 Products

The products from the depleted $UF_6$ conversion process are U metal and anhydrous HF. The annual quantities of each product are presented in Table 2.

**Table 2. Annual Product Quantities**

| Product | Annual Quantity* |
|---|---|
| U metal | 13,500 tonnes |
| Anhydrous HF | 6,800 tonnes |

* Assumes no losses

## 1.4 Depleted $UF_6$ Consumption

The conversion facility was sized to convert an inventory of 400,000 tonnes over 20 years. At the completion of the study, a better estimate of the inventory was developed, and it was found to be nearer 575,000 tonnes. It was estimated that the additional inventory could be processed with a minimal increase in equipment (INEL 1994).

## A. ENVIRONMENT, SAFETY, AND HEALTH (ES&H)

The construction and operation of a depleted $UF_6$ conversion plant in the United States would be regulated by 10 CFR Part 40, *Domestic Licensing of Source Material,* which covers environmental, safety, and health issues. The following related issues were identified during the preconceptual design (INEL 1994):

> The process will contain gaseous hydrogen at high temperature. A leak has the potential to cause an explosion. The risk is comparable to many chemical process industries and must be managed carefully in design.
>
> Fire prevention and protection must be a critical element of the design, because uranium is pyrophoric and there exists a potential for hydrogen gas releases...
>
> HF is extremely toxic and dangerous to handle. Although there are industrial procedures for handling HF, the combination of high-temperature, positive and negative pressures, and ignitable materials make safety designs a crucial part of any process design.

ES&H issues would be addressed by the appropriate designs and operational procedures.

## B. WASTE MANAGEMENT

The process concept does not have any associated major uranium waste streams. In particular, no magnesium fluoride ($MgF_2$) slag stream characteristic of metallothermic reduction routesis generated. The air treatment facilities will generate secondary wastes, but the nature and quantity of these secondary wastes have not been determined.

## C. COSTS

### C.1 Life-Cycle Cost

The plant capital cost was estimated to be $347 million; the plant annual operating cost was estimated to be $38 million; and the development/demonstration cost was estimated to be $56 million. In addition, a decontamination/decommissioning cost of $19 million was estimated. For 20 years' operation, the estimated life-cycle cost is $1.2 billion (INEL 1994)

### C.2 Unit Product Cost

Based on the life-cycle cost and the 20-year production campaign , a unit product cost for the metal of $4.30/kg can be derived.

### C.2 By-product Revenue

The campaign revenues (20 years) from the sale of the anhydrous hydrogen fluoride (AHF) are estimated to be in the range of 100-150 million dollars, or roughly $0.4-0.6/kg-U metal.

## D. TECHNICAL MATURITY

The plasma process for converting of $UF_6$ to uranium metal is in the very early stage of development. Bench-scale experiments generating small quantities of metal have demonstrated basic feasibility (INEL 1994). A sequence of development, engineering, and integrated test activities are required to evaluate the commercial viability of the process (INEL 1994).

## E. SOCIOECONOMICS

### E.1 Employment

The total personnel (operations/maintenance/administrative) is estimated from the data (INEL 1994) to be between 100 and 150.

### E.2 Public Acceptance

This requires evaluation. A plant with potentially lower waste generation than the traditional metal process is expected to have better public acceptance.

### E.3 Local/Regional Development

This requires evaluation. The plant is not expected to have a major impact on the area employment level. However, the introduction of an advanced processing technology could generate new spin-off industries in the area.

## REFERENCES

Idaho National Engineering Laboratory. 1994. *Depleted Uranium Plasma Reduction System Study* (DRAFT), INEL-94/0030.

Los Alamos National Laboratory, 1994. "Depleted Uranium Metal Preparation Using Hydrogen Plasma Technology", *Intelligent Automation and Soft Computing*, pp. 319-324.

Recommendation Response: Mr. Dennis R. Floyd, Manufacturing Sciences Corporation, submitted December 10, 1994. Contains a description of the LANL hydrogen plasma method for uranium metal production.[1]

Recommendation Response: Mr. William Quapp, Idaho National Engineering Laboratory, submitted December 5, 1995, subject: Federal Register Rquest for Recommendations - WJQ-69-94.[2]

[1] RFR Document #8
[2] RFR Document #4

# INFORMATION PACKAGE
# 5

# Continuous Metallothermic Reduction to Uranium Metal

This information package was prepared to describe potential uses or technologies that could facilitate the long-term management of depleted $UF_6$. The application described in this package was not included among the responses to the Department of Energy's Request for Recommendations. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; they are intended to provide sufficient information to assist the Independent Technical Reviewer.

# CONTINUOUS METALLOTHERMIC REDUCTION TO URANIUM METAL

## 1. OVERVIEW

The Ames process, described in Information Package 3, is the standard industrial method for producing uranium (U) metal. Briefly, the process feedstock uranium tetrafluoride ($UF_4$) is produced by the hydrogen reduction of uranium hexafluoride ($UF_6$) in a tower reactor. The uranium metal is produced in a batch process by the magnesium (Mg) reduction of uranium tetrafluoride($UF_4$) in a sealed reactor vessel.

$$UF_4 + 2Mg \text{ ------> } U + 2MgF_2$$

A continuous process for the Mg reduction of $UF_4$ is being developed to provide a uranium/iron (Fe) metal alloy for the Uranium-Atomic Vapor Laser Isotope Separation (U-AVLIS) process. The alloy produced in this continuous metallothermic reduction (CMR) process is ≥ 95 weight percent uranium. Due to the intrinsically higher throughput rate, the continuous process entails significantly lower capital and operating costs than the standard batch process. As currently being developed, the continuous process would have to be modified to produce the pure uranium metal specified for most dense material and radiation shielding applications, rather than the U/Fe alloy.

## 2. PROCESS DESCRIPTION

The design (Figure 1) is based on a top pot with an inner reaction vessel that is precharged with the U/Fe alloy and an inert chloride salt (e.g., calcium chloride), which serves to lower the operating temperature of the system to about 1300° K. The vessel is continuously fed a blended powder mixture of $UF_4$, Mg, Fe, and chloride salt from the top. Three layers are present at steady state as a result of the significant density differences. The top layer is a pool of liquid magnesium which provides the first contact with the powdered feed. The reduction reaction takes place within this top layer, which is maintained by feeding Mg in slight stoichiometric excess to replace that consumed by reaction. The middle layer is a molten mixture of the $MgF_2$ by-product and the chloride salt. The bottom layer is the very dense, molten U/Fe alloy. The molten salt overflows continuously as it is withdrawn and is continuously replenished as the feed blend is added. Droplets of uranium and the alloy formed in the magnesium layer flow down

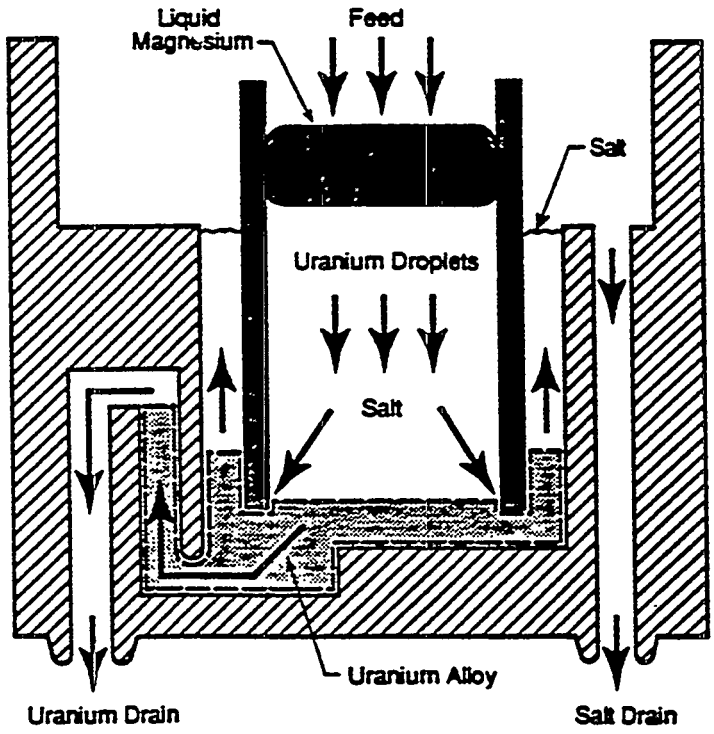


Figure 1. Schematic of Uranium Metallothermic Reactor

through the salt until they reach the bottom, where homogenization occurs. The U/Fe alloy is continuously withdrawn from the bottom and semi-continuously cast into the desired shape.

After solidification and cooling, the water-soluble chloride salt is recovered for recycle to the reactor. If the uranium level in the $MgF_2$ is below about 100 ppm, it can be disposed of in a sanitary landfill. If not, the $MgF_2$ is first decontaminated by leaching and then disposed of in a sanitary landfill.

## 3. PRIMARY MATERIAL FLOWS

For the same annual product (metal) output, the primary inputs ($UF_6$, $H_2$ [$NH_3$], and Mg) are nearly the same as the batch Ames process quantities (Information Package 3). The required $UF_6$ is about 3% less, due to the higher yield for the continuous process. For an assumed annual metal output of 10,000 tonnes, the annual input of $UF_6$ is about 14,900 tonnes.

## 4. TECHNICAL STATUS

Pre-prototype reactor units (6 inch diameter) have been operated at design specific throughputs (2.5 kg U/hour/in$^2$) for short periods. The uranium contamination level of the $MgF_2$ has been established to be typically two orders of magnitude less than that found in the $MgF_2$ slag from the batch reduction route. As a result of the low uranium contamination levels, considerably less leaching is required to ensure that U contamination limits are met in the slag. Remaining engineering development and testing activities include the following:

- Verification of the reference material (graphite) for the long-term containment of the molten salt and uranium.
- Evaluation of the magnesium vapor control and diluent salt options.
- Determination of the build-up rate of oxide and oxy-fluoride impurities.
- Precise assessment of uranium contamination levels in the by-product salt.

Eventual piloting of the system in industry is anticipated to take 2-3 years.

There has been no parallel work to modify and test the continuous process for the production of pure uranium metal. This process would require higher operating temperatures. Several design options exist, and it would take about 2 years to establish process feasibility and to establish initial design parameters. The overall risk is judged to be moderate.

## 5. POTENTIAL BENEFITS

For comparable reactor sizes (diameter), the continuous process offers an order-of-magnitude higher throughput rate than the batch process. The batch process requires a multi-hour heat-up cycle, and, after reaction (a fraction of an hour), a multi-hour cool-down cycle. For the same annual output, the higher throughput for the continuous process translates into many fewer reactors and therefore lower capital costs (equipment and facility) than the batch process. The continuous process is less labor intensive due to both the fewer reactors and the longer periods between refurbishment. This, along with other factors, would result in lower annual operating costs. The much lower uranium level of the $MgF_2$ by-product for the continuous process implies a lower by-product treatment cost. Finally, the continuous process enables semi-continuous casting, without ingot remelt as required by the batch process. This is particularly advantageous (in terms of lower costs and less scrap generation) if the manufacturing is carried out in the same facility.

## REFERENCES

LLNL and Martin Marietta Energy Systems, "Production of Uranium-Iron Alloys by Continuous Metallothermic Reduction of Uranium Tetrafluoride", L-15028, September 1992.

Martin Marietta Energy Systems, "Demonstration of Pilot-Scale Production of Uranium AVLIS Feedstock by Continuous Reduction of Uranium Tetrafluoride", Y/DV- 1323, September 30, 1993.

# INFORMATION PACKAGE

# Conversion to Ceramic $UO_2$ - Existing Industrial Routes

## Combination Package of:
## 6 Dry Process (Integrated Dry Route)
## 7 Wet Process (Ammonium Diuranate )
## 8 Wet Process (Ammonium Uranyl Carbonate)

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# CONVERSION TO CERAMIC $UO_2$ - EXISTING INDUSTRIAL ROUTES

## 1.0 OVERVIEW

Uranium dioxide ($UO_2$) in the stabilized ceramic form as pellets or small particles has a density about three times that of normally compacted $UO_2$ or tri-uranium octaoxide ($U_3O_8$). A higher density would allow a proportionally lower disposal volume and a lower volume of Ducrete (DU loaded concrete) for the same radiation shielding . The conversion of isotopically enriched uranium hexafluoride ($UF_6$) (3-5 % U-235) to ceramic $UO_2$ is practiced in the commercial fuel fabrication industry. By either a "wet" or "dry" process, the $UF_6$ is chemically converted to a $UO_2$ powder under very controlled conditions to ensure suitable powder properties. After milling, sieving, and addition the of a lubricant, the powder is compressed under high pressure into pellets. The pellets are finally sintered to yield a solid, which is typically 95% of theoretical density (10.97 $g/cm^3$).

All existing industrial routes share the same basic physical technologies (pressing and sintering) for converting the powder into the ceramic form. Accordingly, the following describes only the chemical conversion steps. It should be noted that there are multiple variations on each of the processes, and they differ from one fabricator to another. However, much of the specific information is proprietary and cannot be included.

## 2.0 PROCESS DESCRIPTIONS

### 2.1 Commercial Wet Processes

All wet processes share an initial precipitation step. The two processes of major importance are the ammonium diuranate (ADU) process and the ammonium uranyl carbonate (AUC) process. The ADU process is the most commonly used and is practiced in both the U.S. and Europe. The AUC process is practiced in Europe, but not domestically. These aqueous processes can be used for both $UF_6$ and uranyl nitrate solutions as input streams.

### 2.1.1 ADU Process

The ADU route (Figure 1) first involves the hydrolysis of $UF_6$ to uranyl fluoride ($UO_2F_2$). This is followed by the addition of ammonium hydroxide to precipitate the uranium as uranium diuranate,( $[NH_4]_2U_2O_7$). After centrifuge separation from the liquid, the ADU slurry is dried. The ADU is then calcined to uranium trioxide ($UO_3$) or $U_3O_8$, which in turn is reduced by hydrogen to $UO_2$ powder. Often the calcination and reduction steps are carried out in the same reactor (calciner), and the intermediate uranium oxide is not isolated.

### 2.1.2 AUC Process

As in the ADU method, the $UF_6$ is first hydrolyzed to uranyl fluoride. By the addition of ammonia ($NH_3$) and carbon dioxide ($CO_2$), the uranyl fluoride is precipitated as ammonium uranyl carbonate, ( $[NH_4]_4U_2O_7$). After filtration and drying, the AUC is calcined in the presence of hydrogen to $UO_2$ powder.

The AUC process has several demonstrated advantages over the ADU process, including the following: (1) the AUC precipitate is more crystalline, allowing easier filtration and washing, and (2) the larger AUC precipitate particles decompose into oxide powders that are more suitable for pellet fabrication without preliminary granulation or milling operations. On the other hand, the much larger stoichiometric excesses of chemicals ($NH_3$ and $CO_2$) required for the AUC process generate comparatively large amounts of gaseous and dissolved solids as wastes.

## 2.2 Commercial Dry Processes

In recent years, fuel fabricators have increasingly turned from wet to dry routes when replacing or expanding capacity. The dry processes have substantially fewer steps and fewer waste treatment and recycle requirements. Dry processes only work with $UF_6$ and, at least for internal scrap recovery, need an aqueous line for nitrate conversion.

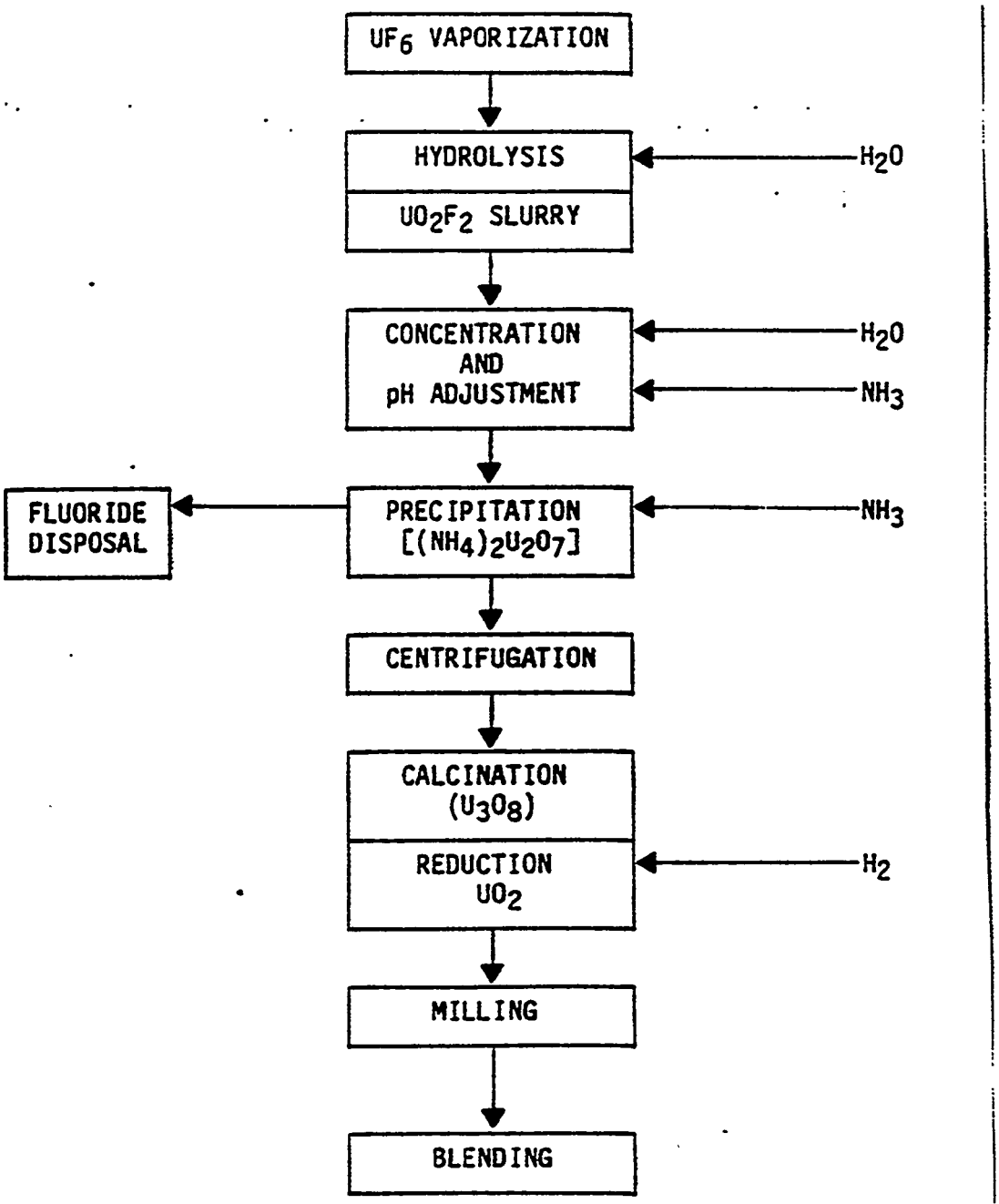


Figure 1. ADU Wet Process

### 2.2.1 Integrated Dry Route (IDR)

As in the case of wet routes, there are variations in the dry process, including the number of stages and the type of reactor (rotary kiln or fluidized bed). The process pioneered by British Nuclear Fuels Limited (BNFL) is the integrated dry route (Figure 2). In this process, $UF_6$ is converted directly to ceramic grade powder by reaction with steam and hydrogen in a rotary Inconel kiln. The kiln is operated with countercurrent gas solids flow, with $UF_6$ being fed with steam in the base of a filter hopper at the gas outlet end of the kiln. The $UF_6$ reacts with the steam to produce solid uranyl fluoride, which passes into the kiln by means of a scroll feeder. Reduction of the uranyl fluoride is achieved by a hydrogen/steam feed to the powder discharge end of the kiln. Effluent gases (HF and water) pass through a filter system prior to discharge to an operation for recovering of the hydrofluoric acid.

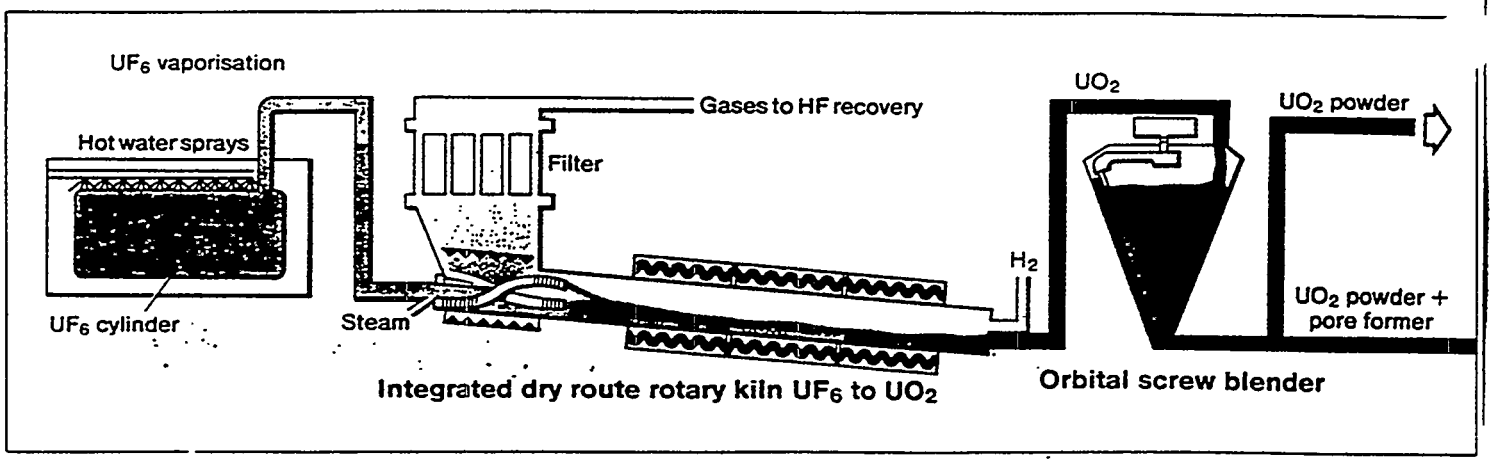


Figure 2. IDR Process

### 2.3 Uranium Oxide Pellet Manufacture

The uranium dioxide produced by the ADU, AUC, and IDR processes is a fine powder which must be consolidated into a dense form for application and use. This is normally accomplished by pelletization. Most of the densification experience is based upon fuel use. Non-fuel applications of dense uranium dioxide, for example shielding, would not require tolerances as stringent as those for fuel applications.

Pelletization involves as many as 20 steps. These discrete operations ultimately convert the fine, low density powder into a dense, cylindrical pellet that measures approximately 1/4 in diameter by ½ high. Often, specific details of the processing steps are proprietary and application-dependent, based upon empirical testing and years of experience.

Initially, various blending and milling operations incorporate additives into the powder to ensure homogeneity. Additives include pore formers, binders, and surface modifying agents. Sometimes burnable neutron poisons are also introduced. In small quantities, these provide for refined control of reactivity and uniformity along the length of the fuel rod. Neutron poisons would not be used for depleted uranium applications. The powder mixture is granulated by either slurrying in water and drying, or by pressing the powder and then fracturing the resulting briquettes. The granules are sieved and classified by size. The granulated powder is poured into pressing dies and compressed in multi-press stations. The resulting "green" pellets are heated to 300-500°C to remove organic compounds and then loaded onto trays (also called "boats" manufactured from molybdenum). A push-pull in a 1,000-1,100°C furnace sinters the uranium dioxide under a slightly reducing atmosphere of 2-4% hydrogen in argon. Sintering collapses pores and void spaces within the pellet and results in shrinkage and densification. Pelletizing achieves 90- 95% of the theoretical density. The pellets are mechanically removed from the dies and the boats and sized. Machining operations match the pellet sizes to the specific tolerances required. Analytical stations verify the assay content, uniformity, and consistency against the specifications. For fuel applications, the pellets are subsequently loaded into fuel rods.

## 3.0 $UF_6$ FEED REQUIREMENTS

All $UO_2$ conversion processes have very high uranium yields which, for scoping purposes, can be assumed to be unity. Accordingly, 1.00 kg $UO_2$ product requires 1.30 kg $UF_6$ feed. For the dry process, 0.44 kg hydrofluoric acid (as HF) by-product would be produced. In principle, the acid could be upgraded to anhydrous hydrogen fluoride (AHF) by one of several processes, including distillation.

## 4.0 DOMESTIC CAPACITY

The existing fuel fabrication plant capacity for converting enriched $UF_6$ into ceramic $UO_2$ is roughly estimated as 5,000 tonnes $UF_6$ annually. There appears to be little excess capacity, and the practicality of dual use of the same equipment for both enriched and depleted uranium is uncertain. Conversion of the entire depleted $UF_6$ stockpile into ceramic $UO_2$ over 20 years would require conversion capacity of 28,000 tonnes $UF_6$ annually; therefore, any significant demand for depleted $UO_2$ (ceramic) would require new capacity.

## 5.0 NEW CAPACITY - PROCESS SCALING

For depleted uranium, the chemical process equipment for the conversion from $UF_6$ to the $UO_2$ powder can be significantly scaled back as there are no criticality constraints. Accordingly, this would enable a reduction in the unit cost for the chemical conversion operations. However, it is unclear that the same thing applies to the more costly physical manufacturing steps (pressing and sintering) that are currently used to convert the powder into the ceramic form. Higher-throughput/lower-cost pelletizing technologies are of interest. In addition, advanced conversion processes with intrinsic features to reduce the manufacturing requirements are of particular interest. Gelation, an advanced process, is described in Information Package 11.

## 6.0 ENVIRONMENT, SAFETY, AND HEALTH

All the processes described in this information package involve standard industrial practices. Although the wet ADU process has been the most commonly used, the IDR process is replacing ADU for facility upgrades or expansions. Dry processes such as IDR are simpler and generate less waste.

Any significant demand for depleted $UO_2$ (ceramic) would require new capacity. The construction and operation of a $UO_2$ conversion facility in the United States would be regulated by 10 CFR Part 40, *Domestic Licensing of Source Material*, which establishes procedures and criteria for the issuance of licenses to receive, possess, use, transfer, or deliver source and by-product material.

## REFERENCES

Nuclear Chemical Engineering (second edition), Benedict, Pigford, and Levi, McGraw-Hill.

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# INFORMATION PACKAGE
# 9

# Conversion to Ceramic $UO_2$: Gelation

This information package was prepared to describe potential uses or technologies that could facilitate the long-term management of depleted $UF_6$. The application described in this package was not included among the responses to the Department of Energy's Request for Recommendations. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; they are intended to provide sufficient information to assist the Independent Technical Reviewer.

# *CONVERSION TO CERAMIC $UO_2$ - GELATION*

## 1. OVERVIEW

This information package briefly describes conversion routes to dense ceramic uranium dioxide based upon gelation methods. It also provides summary information on the technical maturity, potential capacity, and environmental impacts of gelation technology, to assist in the evaluation of this option for the U.S. Department of Energy (DOE).

Most applications of uranium depend upon its high density, either for fuel efficiency, thermal conduction, or attenuation effects (shielding, absorption, etc.) (Reference 1). Uranium dioxide ($UO_2$) is an ideal form for many applications because it can be converted into a high density material. The principal approach used world-wide in the commercial nuclear fuel industry for attaining high density uranium dioxide involves complex powder blending followed by mechanical pressing into dies and a long sintering step. This approach is time consuming, mechanically intensive, throughput limited, and relatively expensive (Reference 2). Consequently, during the 1970s and early 1980s, several alternative routes to uranium dioxide were postulated and tested. These routes were based upon process industry methods that avoided mechanically complex operations. Many programs were conducted in the U.S. and Europe for developing and testing these less mechanical alternative processes, and numerous descriptions exist (for example, References 2-6).

The alternative processes are collectively termed "gelation" and are variously known as sol-gel, gel-precipitation, internal gelation, external gelation, particle fuel, microsphere, and solution precipitation. All of these processes use hydrodynamics to form spheres of ammonium diuranate (ADU), which are subsequently cured, dried, and sintered directly into dense uranium dioxide microspheres ranging from 30 to 1,500 microns. These spheres were to be loaded into fuel rods using vibratory methods. At the time, the intention was to use gelation methods to produce mixed oxide fuels for plutonium recycle and breeder fuel cycles, with the subsequent replacement of the existing mechanical routes during fabrication plant expansions. The abandonment of fuel recycle in the U.S. and the 60%-lower-than-expected growth in the nuclear industry did not allow the implementation of gelation methods.

Gelation is an approach to uranium hexafluoride conversion that DOE is considering for part of its Depleted Uranium Hexafluoride Management Program. Gelation includes oxide routes (described in this information package) and carbide routes (Information Package 10). Gelation is not specifically mentioned in responses received from the public and private industry, but offers potential benefits for depleted uranium (DU) applications.

## 2. PROCESS DESCRIPTION

Figure 1 provides a simplified block diagram of the gelation process, as applied to depleted uranium hexafluoride. The hexafluoride would be reacted with steam to produce uranyl fluoride and hydrogen fluoride; the latter should be recoverable in the anhydrous form. The solid uranyl fluoride would be collected and dissolved in water. Some adjustment of the residual hydrogen fluoride concentration by distillation may be necessary. Fluorides should not affect the gelation reactions, and removal would be expected in the aging step. However, most of the experimental testing has focused on the use of nitrate solutions (References 2-6), and this is assumed as the baseline approach.

Thus, the next step would use calcium nitrate to precipitate the fluoride and form uranyl nitrate in solution. The nitrate solution is subsequently clarified and concentrated, chilled, and combined with "gel formers." These gel formers are polymeric-like agents that modify surface tension (e.g., for external gelation routes) or ammonia-releasing compounds (e.g., internal gelation routes). External gelation routes frequently use gaseous ammonia, while internal routes use amines, such as HMTA (HexaMethyleneTetraAmine).

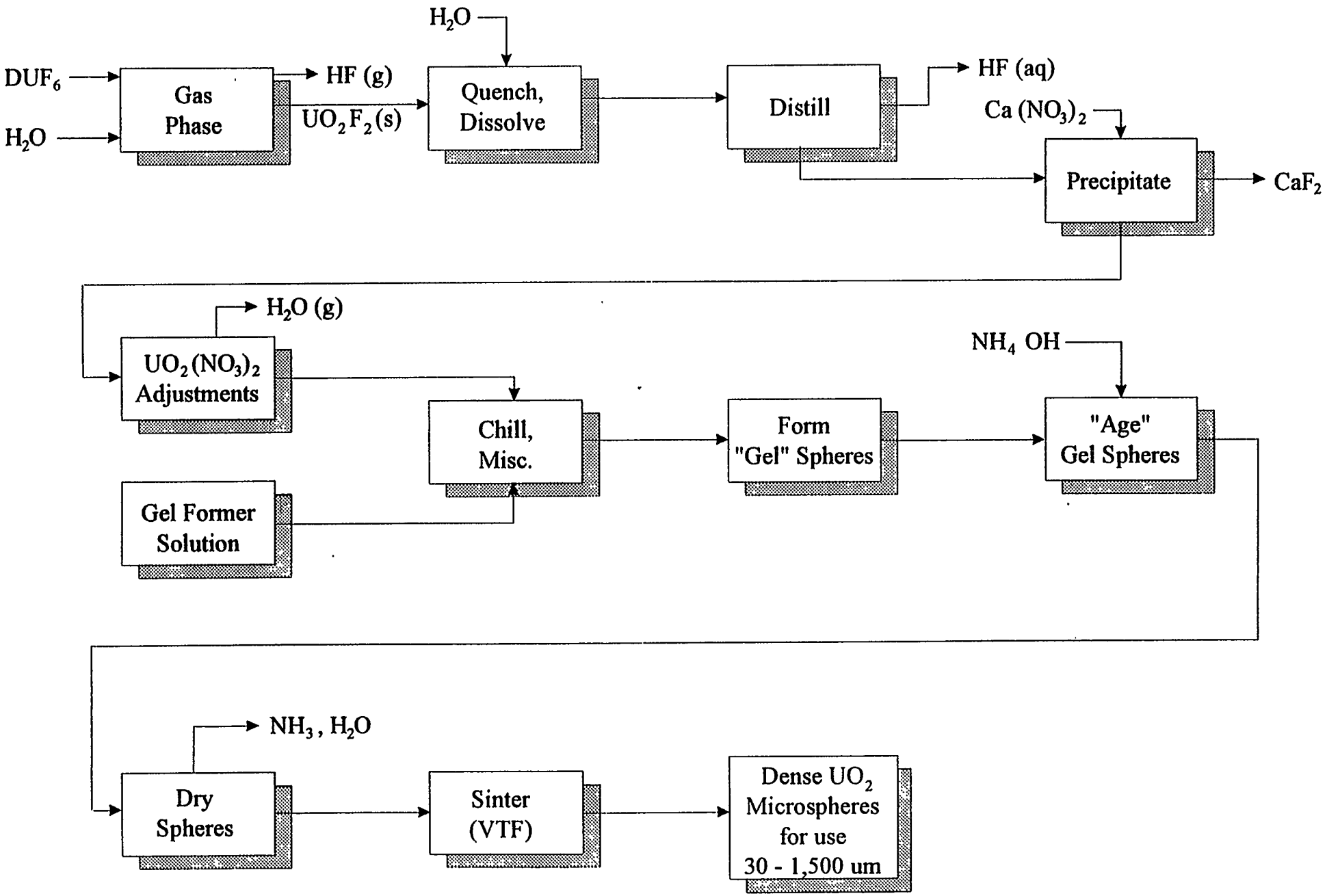
Gel formation utilizes surface tension phenomena to shape solution droplets into spheres. Vibrating nozzles fragment the uranyl nitrate/gel-former solution mixture into a stream of liquid droplets that falls vertically within a cavity. The size of the nozzles and the vibration frequency determine the droplet sizes and, ultimately, the final microsphere sizes. The droplets assume the shape of least resistance, which is a perfect sphere. The cavity is usually a vertical column that allows time for sufficient ADU formation to occur and provides enough strength to avoid sphere deformation at the bottom. Column heating to 50-100°C increases the formation reaction. Gel spheres are fragile and require careful handling to avoid breakage.

External gelation routes use ammonia in the column, and, thus, the gel spheres fall through a gas. Spheres are collected in a solution of ammonium hydroxide at the bottom of the column, and allowed to "age" (i.e., complete the ADU precipitation). These green spheres are periodically removed and washed with fresh ammonium hydroxide solution. External gelation requires careful design for generating larger spheres (usually greater than 800 microns in diameter) due to size effects upon mass transfer. In contrast, internal gelation utilizes aqueous phase immiscibility in an organic liquid for sphere formation, which allows for better heat transfer and shorter columns with longer residence times. Organic oils and solvents have been used as the liquid phase. The gel spheres are subsequently transferred from the column and aged in an ammonium hydroxide solution. Internal gelation produces uniform microspheres and is less affected by size.

After aging, the gel spheres are designated "green" spheres. They are dried at low temperatures to remove water and excess ammonia. Subsequently, a vertical tube furnace sinters the microspheres

under an argon-hydrogen atmosphere. The final sintered spheres have densities usually exceeding 95% of the theoretical density for uranium dioxide. If two or three sizes of microspheres are produced, spatial densities exceeding 90% of theoretical can be obtained by vibratory loading methods.

# Figure 1. Gelation Route to Dense $UO_2$



## EVALUATION FACTORS

### A. ENVIRONMENT, SAFETY, AND HEALTH ISSUES

Analyses specific to the gelation processes have not been performed, and no information is available for specific factors. However, by analogy, the environmental, safety, and health issues are expected to be similar to, but lower than, existing mechanical pellet-based plants (Reference 2). This estimate is based on similarities in the unit operations and more confinement of the materials due to the use of process equipment.

External gelation routes use gaseous ammonia, which requires handling precautions. These precautions are adequately addressed by chemical industry practices and the procedures at existing plants with ADU lines.

Internal gelation routes use organic oils and solvents. Historically, tests have used mineral oils, silicon oils, perchlorethylene, trichloroethylene, and mixtures thereof (References 2-6). The Oak Ridge (ORNL) experiments used trichlorethylene (Reference 2). The oil or solvent provides immiscibility, residence time, and heat transfer. If other oils or solvents are needed for regulatory purposes, finding one should not be a major concern. Hydrocarbon diluents used in reprocessing and heat transfer fluids would appear to be likely replacements. It should be noted that most existing pellet plants include a solvent extraction system for uranium recovery from effluents, waste streams, and "dirty" scrap.

### B. WASTE MANAGEMENT

Specific analyses of waste generation have not been performed for gelation-based processes. By analogy to operations, waste management at a gelation plant is expected to be comparable to, or lower than, that at an ADU/pelletizing plant (Reference 2; also see Information Package 6/7/8). Uranium carryover and losses to waste streams and effluents should be smaller, due to the quantitative nature of gelation precipitation.

### B. COSTS

No data is available at this time.

### D. TECHNICAL MATURITY

The various gelation processes have been tested in the laboratory and in pilot plant studies (References 2-6). Multiple kilogram quantities of microspheres have been produced. Designs for larger plants have been generated, but none have been built (References 2-6). It should be

anticipated that refinements in the gelation routes and some further developmental efforts will be necessary before a large plant could be built for depleted uranium use. Specific estimates for time and funding have not been developed for DU gelation methods, but, by analogy to the programs discussed in Reference 2, these efforts should require relatively modest funding (probably not exceeding $10 million) and be completed in under five years.

Capacity and Potential DU Hexafluoride Consumption

Gelation routes were pursued because they offered significant automation and throughput advantages over mechanical, pellet-based processes (References 2-6) potentially a five-to ten-fold increase for a plant of the same footprint. Thus,to convert the depleted uranium hexafluoride to ceramic uranium dioxide over a 20-year period, the gelation plants with an approximate capacity of 28,000 MT $UF_6$/yr would not exceed the size of the existing pellet-based dense uranium dioxide plants (these have a combined annual capacity of around 5,000 MT/yr). The selected application(s) of dense uranium dioxide would determine the actual throughput.

## E. SOCIOECONOMICS

Employment data, formal evaluation of public acceptance, and local and regional development resulting from construction and operation of a gelation facility cannot be measured at this time.

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# INFORMATION PACKAGE

## Conversion to Uranium Carbide

## Combination Package of:
## 10 Graphite Approach
## 11 Gelation Approach

This information package was prepared to describe potential uses or technologies that could facilitate the long-term management of depleted $UF_6$. The application described in this package was not included among the responses to the Department of Energy's Request for Recommendations. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; they are intended to provide sufficient information to assist the Independent Technical Reviewer.

# CONVERSION TO URANIUM CARBIDE - GRAPHITE AND GELATION APPROACHES

## 1. OVERVIEW

This information package briefly describes conversion routes to dense uranium carbide based upon graphite and gelation processes. It also provides summary information on the technical maturity, potential capacity, and environmental impacts of these technologies, to assist in the evaluation of this option for the U.S. Department of Energy (DOE).

Many applications of uranium depend upon its high density, either for fuel efficiency, thermal conduction, or attenuation effects (shielding, absorption, etc.). Uranium carbides have the highest densities of any uranium compounds (References 1 and 2) and have been frequently mentioned as potential reactor fuels for certain high temperature reactors (Information Package F1).

There are two principal routes for manufacturing uranium carbide fuels. The historical route utilizes the reduction of uranium dioxide with carbon (e.g., from graphite). The uranium dioxide would be manufactured from uranium hexafluoride or uranyl nitrate solutions. Gelation routes to uranium carbides have also been proposed and tested. These routes are variously known as sol-gel, gel precipitation, internal gelation, external gelation, particle fuel, microsphere, kernel, and solution precipitation processes. All of these gelation processes use hydrodynamics to form spherical shapes of ammonium diuranate (ADU), which are subsequently cured, dried, and reduced by sintering into the carbide itself.

The carbide gelation process starts from a nitrate solution to make uranium dioxide, and is modified by adding carbon to the broth or sol to yield the carbides. The gelation process was experimentally active in the late 1970s, as an alternative to the graphite process. The manufacture of uranium carbides by either of these routes is not as well developed and implemented as routes for manufacturing uranium dioxide.

The conversion of uranium hexafluoride to carbides is a conversion approach that DOE is considering for part of its Depleted Uranium Hexafluoride Management Program. Carbides are not specifically mentioned in responses received from the public and private industry, but they offer potential benefits for DU applications.

## 2. PROCESS DESCRIPTIONS

Uranium carbides are usually manufactured in spherical shapes and then assembled into a form. Essentially all previous uses of uranium carbides have focused on nuclear fuel applications; thus, the spheres would be assembled into fuel rods.

### 2.1 Graphite Route to Uranium Carbides

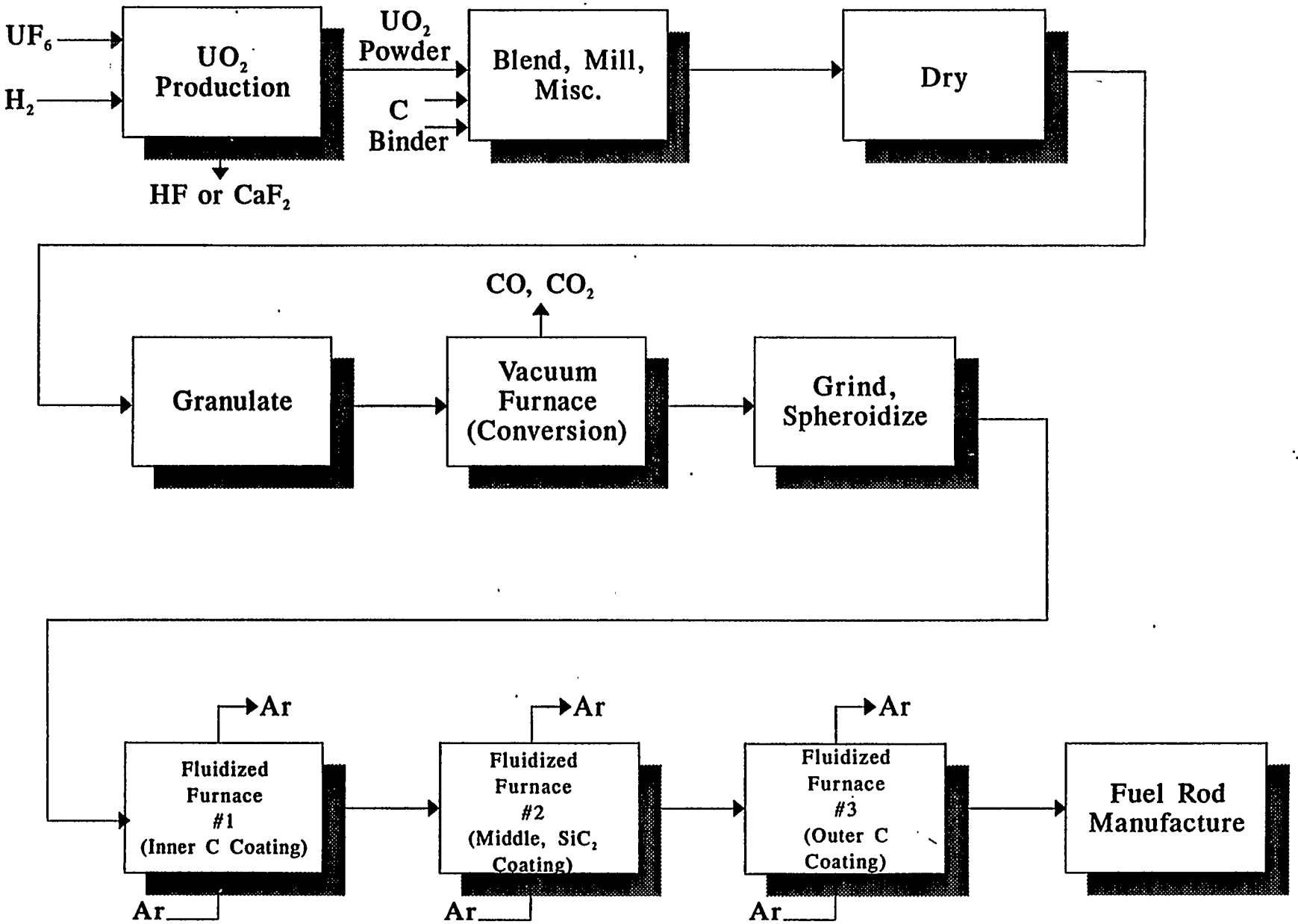
Figure 1 outlines the graphite route for manufacturing uranium carbides. Depleted uranium hexafluoride would be converted into uranium dioxide powder by various contacting methods with steam and hydrogen. Either wet processes (e.g., ADU, AUC) or dry processes (e.g., IDR) could be used (see Information Package 6/7/8). The uranium dioxide ($UO_2$) powder becomes the starting material for kernel (microsphere) production (References 1, 3, and 4).

The uranium dioxide powder is mixed with carbon flour and an ethylene binder to form a slurry, which is oven dried and milled to sand-sized particles. The oxides are converted to carbides in a vacuum heating step. As a result of this vacuum heating, the oxygen is replaced by carbon. Carbon monoxide (CO) and carbon dioxide ($CO_2$) are released. The amount of carbon initially mixed with the dioxide determines whether the uranium monocarbide or the uranium dicarbide is formed. The monocarbide is usually preferred because of its higher density. The resulting small particles of uranium carbide are fed through a furnace (operating in excess of the melting point of uranium carbide) to form tiny microspheres. The spherical shape of the carbides is due to surface tension.

Subsequently, coatings are applied to the microspheres in a fluidized bed furnace. These coatings effectively isolate the uranium carbide from the environment at the microscopic level. Three-layer coatings are frequently used, and are the basis for this discussion (References 3, 4, and 5). In the first high temperature furnace, a stream of inert gas (usually argon) levitates and heats the carbide spheres. A mixture of hydrocarbons is introduced into the gas stream and dissociates upon the surface of the spheres. This forms a dense, pyrolytic carbon layer for fission product retention and isolation from the atmosphere. Periodic elutriation transfers the microspheres to a second fluidized furnace, where a dense silicon carbide coating is applied by decomposition. In a third fluidized bed reactor, another coating of pyrolytic carbon is applied.

The resulting coated spheres are assembled into fuel rods for reactor use (see Section 2.3 and Information Package F1). Other types of fuel materials (e.g., thorium) may be incorporated into the fuel rod with the spheres. An alternative method for making uranium carbide in the form of low density pellets is described in a 1979 patent assigned to Mitsubishi Atomic Power Industries, Inc., Tokyo (Reference 6).

# Figure 1: Graphite Route for Uranium Carbide Production



## 2.2 Gelation Route to Uranium Carbides

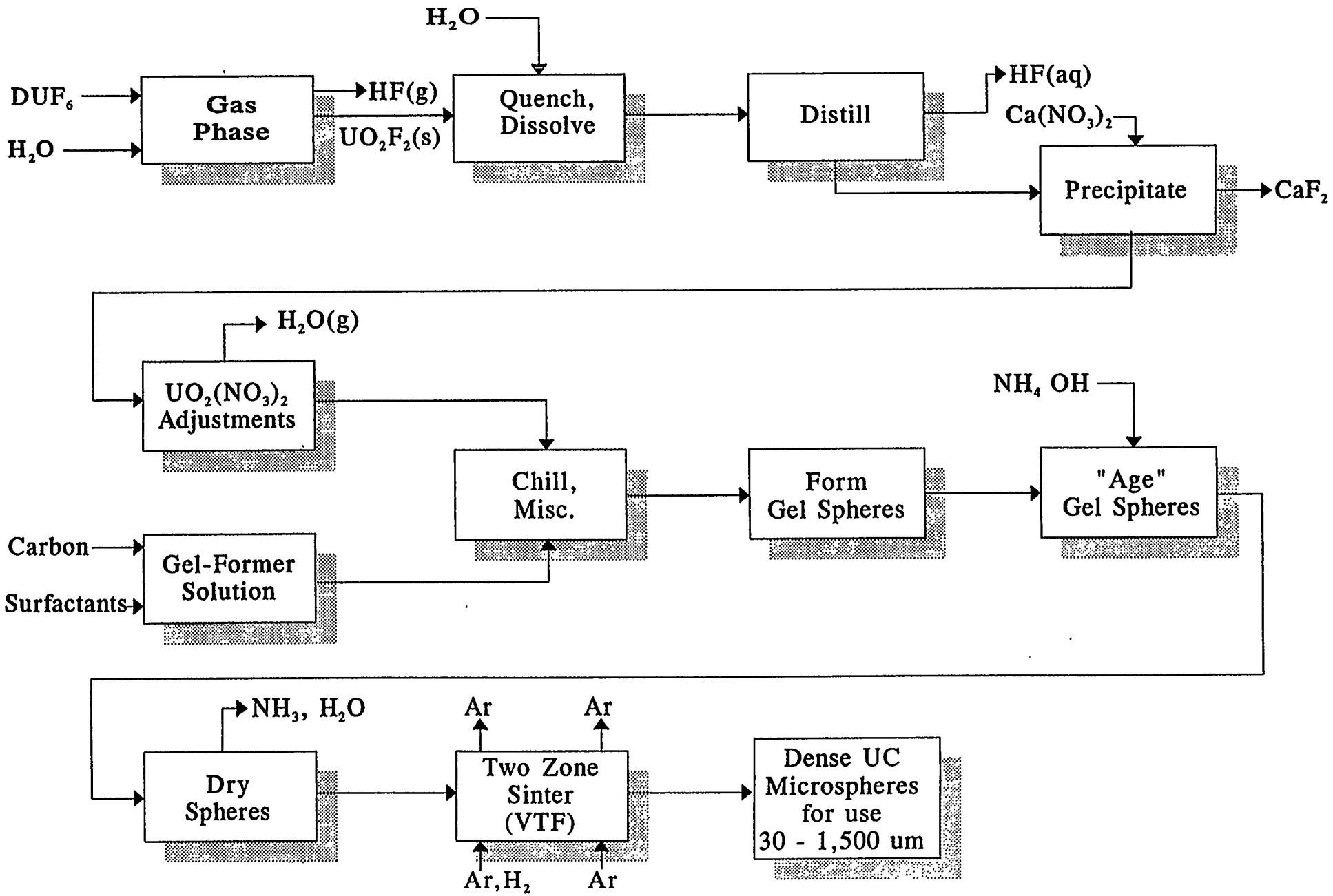
Figure 2 displays the steps in an alternative carbide route based upon gelation methods. The gelation route to the manufacture of carbides is similar to the standard gelation method for uranium dioxide (References 5, 7-10). The hexafluoride would be reacted with steam to produce uranyl fluoride and hydrogen fluoride; the latter should be recoverable in the anhydrous form. The solid uranyl fluoride would be collected and dissolved in water. Some adjustment of the residual hydrogen fluoride concentration by distillation may be necessary. Fluorides should not affect the gelation reactions, and removal would be expected in the aging step. However, most of the experimental testing has focused on the use of nitrate solutions (References 5, 7-10), and this is assumed as the baseline approach.

Thus, the next step would use calcium nitrate to precipitate the fluoride and form uranyl nitrate in solution. The nitrate solution is subsequently clarified and concentrated, chilled, and combined with "gel formers." These gel formers are polymeric-like agents that modify surface tension (e.g., for external gelation routes) or ammonia-releasing compounds (e.g., internal gelation routes). External gelation routes frequently use gaseous ammonia, while internal routes use amines, such as HMTA (HexaMethyleneTetraAmine). The gel-former solution also includes carbon, added in a fine particulate form (e.g., carbon black, fine graphite). The quantity of carbon added depends upon the desired final carbide (monocarbide or dicarbide), and is usually between 14% and 25% by weight. Consequently, surfactants are added to the solution to stabilize the carbon particles and keep them in suspension.

Gel formation utilizes surface tension phenomena to shape solution droplets into spheres. Vibrating nozzles fragment the uranyl nitrate/gel-former solution mixture into a stream of liquid droplets that fall vertically within a cavity. The size of the nozzles and the vibration frequency determine the droplet sizes and, ultimately, the final microsphere sizes. The droplets assume the shape of least resistance, which is a perfect sphere. The cavity is usually a vertical column that allows time for sufficient ADU formation to occur and provide enough strength to avoid sphere deformation at the bottom. Column heating to 50-100°C increases the formation reaction. Gel spheres are fragile and require careful handling to avoid breakage.

External gelation routes use ammonia in the column, and, thus, the gel spheres fall through a gas. Spheres are collected in a solution of ammonium hydroxide at the bottom of the column, and allowed to "age" (i.e., complete the ADU precipitation). These green spheres are periodically removed and washed with fresh ammonium hydroxide solution. External gelation requires careful design for generating larger spheres (usually greater than 800 microns in diameter) due to size effects upon mass transfer. In contrast, internal gelation utilizes aqueous phase immiscibility in an organic liquid for sphere formation, which allows for better heat transfer and shorter columns with longer residence times. Organic oils and solvents have been used as the liquid phase. The gel

# Figure 2. Gelation Route to Dense UC



spheres are subsequently transferred from the column and aged in an ammonium hydroxide solution. Internal gelation produces uniform microspheres and is less affected by size.

After aging, the gel spheres are designated "green" spheres. They are dried at low temperatures to remove water and excess ammonia. Subsequently, a vertical tube furnace sinters the microspheres under an argon-hydrogen atmosphere. A two-zone furnace is usually required for carbides, to avoid over-reduction of the uranium. The first zone utilizes an argon carrier gas with 2-4% hydrogen (Reference 5). This is where most of the reaction and generation of carbon monoxide and dioxide occurs. The second zone operates at higher temperatures, uses argon as the cover gas, and results in sintering and the high densities desired. The final sintered spheres have densities usually exceeding 95% of the theoretical density for uranium carbides. If two or three sizes of microspheres are produced, spatial densities exceeding 90% of theoretical can be obtained by vibratory loading methods.

The uranium carbide microspheres would be coated prior to use, in three fluidized bed furnaces. The application of these coatings is identical to that for microspheres produced via the graphite route (Section 2.1).

## 2.3 Fuel Rod and Form Manufacture

The coated uranium carbide microspheres are usually put in a larger form for use, and manufacture frequently uses heat treatments. The larger particles are locked into a mold, and a forming compound is injected to fill the void spaces. For fuel use, this is generally a heated mixture of petroleum pitch and graphite powder, other additives may also be introduced (e.g., fertile materials, such as thorium; see References 3 and 4). After cooling, the "green" rods are ejected from the molds as cylindrical forms and subsequently heated to carbonize the pitch. Other treatments may also be applied.

## EVALUATION FACTORS

### A. ENVIRONMENTAL, SAFETY, AND HEALTH ISSUES

The environmental, safety, and health issues are expected to be similar to, but slightly greater than, those for existing uranium dioxide/mechanical pellet-based plants, due to the larger number of operations involved. Carbides are slightly reactive towards moist air and water, which results in a slow conversion to uranium dioxide (Reference 1). However, this slightly reactive tendency is mitigated by the impervious coatings and the use of process equipment.

External gelation routes use gaseous ammonia, which requires handling precautions. These precautions are adequately addressed by chemical industry practices and the procedures at existing plants with ADU lines.

Internal gelation routes use organic oils and solvents. Historically, tests have used mineral oils, silicon oils, perchlorethylene, trichloroethylene, and mixtures thereof. The ORNL experiments used trichlorethylene. Chlorinated solvents present potential acute and chronic health hazards which are usually mitigated in the plant's layout (e.g., adequate ventilation and carbon absorbers). If possible, the regulators now prefer that such chlorinated solventsbe avoided. The oil or solvent provides immiscibility, residence time, and heat transfer. If other oils or solvents are needed for regulatory purposes, finding one should not be a concern. Hydrocarbon diluents used in reprocessing and heat transfer fluids would appear to be likely replacements. It should be noted that most existing pellet plants include a solvent extraction system for uranium recovery from effluents, waste streams, and "dirty" scrap.

The Nuclear Regulatory Commission (NRC) does not generally exert regulatory licensing authority over DOE, but it does have authority to require DOE "to undertake such monitoring, maintenance, and emergency measures as are necessary to protect the public health and safety...to comply with the standards promulgated pursuant to the Uranium Mill Tailings Radiation Control Act of 1978" (10CFR Ch.I, 1/1/91 edition, 150.15[b][5]).

Exposure limits for uranium hexafluoride, based on acute chemical effects, are established by the NRC in NUREG-1391, "Chemical Toxicity of Uranium Hexafluoride Compared to Acute Effects of Radiation." The IDLH (immediately dangerous to life and health) limit for hydrogen fluoride is chosen as an indicator. This limit is 30 ppm (approximately 25 mg/m3) for 30 minutes, the time in which one should not experience any escape-impairing symptoms. For longer time periods, the equation C=25 mg/m3 (30min/t)1/2 is provided. For eight hours, this equation allows 6.25 mg/m3. A more cautious approach results from considering chronic as well as acute effects, and NIOSH has recommended 3 ppm (approximately 2.5 mg/m3) for eight hours, while ACGIH (American Council of Governmental Industrial Hygienists, a non-regulatory organization) further

reduces the recommended time for 3 ppm exposure to 15 minutes or less. Comparable limits for uranium hexafluoride itself, as soluble uranium, are IDLH=20 mg/m3, the 0.2 mg/m3 eight-hour limit recommended by ACGIH, and OSHA's eight-hour limit of 0.05 mg/m3 (Reference 11).

Uranium carbide, as an insoluble form, is controlled more for radiation than for chemical toxicity (References 11-13). Insoluble uranium compounds have an IDLH of 30 mg/m3 and a recommended eight-hour limit (ACGIH) of 0.2mg/m3.

## B. WASTE MANAGEMENT

Waste management at a graphite to carbide plant is expected to be comparable to existing uranium dioxide fuel fabrication plants (see Information Packages 6/7/8 and D1/F1). No specific analyses have been prepared for gelation processes. However, by analogy, waste management at a gelation plant is expected to be comparable to, or lower than, that of a graphite carbide plant based upon ADU/pelletizing technologies (Reference 5). Uranium carryover and losses to waste streams and effluents should be smaller, due to the quantitative nature of the gelation precipitation.

## C. COSTS

No data is available at this time.

## D. TECHNICAL MATURITY

Uranium carbides have been produced in ton quantities via graphite processes and used in demonstration-size commercial nuclear reactors (References 3 and 4). The various uranium carbide gelation processes have been tested in the laboratory and in pilot plant studies (References 5, 7-10). Multiple kilogram quantities of microspheres have been produced. It should be anticipated that refinements in uranium carbide manufacture and some further developmental efforts will be necessary in graphite and gelation processes before a large plant could be built for depleted uranium use. Specific funding and schedule estimates are not available. However, by analogy to the programs of the late 1970s, relatively modest funding (perhaps $10-20 million) and a relatively short implementation period (5-10 years) would be required to update carbide processes for depleted uranium.

Capacity and Potential DU Hexafluoride Consumption

Only small scale plants have been built and used to produce uranium carbide for fuel applications. By analogy to the uranium dioxide manufacturing approaches and infrastructure, a plant for uranium carbide manufacture will probably be larger (potentially 25-50% larger) than an oxide plant of comparable capacity due to the greater number of processing steps and lines involved. The graphite route contains unit operations and equipment that may not be readily expandable and scalable for large throughputs.

Carbide gelation routes were pursued because they offered significant automation and throughput advantages over the graphite processes (Reference 5). As with oxides, there is potentially a five-to ten-fold increase for a plant of the same footprint. Again, the carbide gelation plant would probably be larger than the oxide gelation plant due to the greater number of processing steps. Conceptually, there are no apparent throughput limitations in the carbide gelation processes. The selected application(s) of dense uranium carbide would determine the actual throughput.

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# INFORMATION PACKAGE
# A1

# Disposal of $U_3O_8$

This Information Package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on Depleted $UF_6$ technologies or applications currently under consideration by the Department of Energy. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; it is intended to provide sufficient information to assist the Independent Technical Reviewer.

# *DISPOSAL OF $U_3O_8$*

## 1. OVERVIEW

This information package briefly describes disposal of depleted uranium in the form of triuranium octaoxide ($U_3O_8$). It also provides supplemental data on environment, safety and health; waste management; cost; technical maturity; and socioeconomics to assist in the evaluation of Request for Recommendation submittals from Idaho National Engineering Laboratory (INEL) and the Nuclear Regulatory Commission (NRC).

The proposed disposal options for the depleted uranium inventory are near-surface, deep geological, or retrievable disposal. Due to the reactive nature of uranium hexafluoride ($UF_6$), depleted uranium would need to be converted to another form prior to disposal. In contrast, $U_3O_8$ is non-reactive under normal environmental conditions and has a very low solubility in water, which are two important characteristics for disposal. This information package discusses the disposal of depleted uranium after it has been converted to $U_3O_8$.[1]

With respect to the radiological and chemical characteristics of depleted uranium and the potential impact on humans, the choice of chemical form for disposal is based on three considerations (Hertzler 1994):

(1) potential release (i.e., solubility and dispersibility),
(2) environmental behavior (i.e., reactivity and solubility), and
(3) relative toxicity in drinking water.

With no additional treatment after conversion, $U_3O_8$ is chemically stable (i.e. non-reactive with very low solubility), with a melting point of 1300°C, at which it decomposes and converts to $UO_2$ (Hertzler 1994, Lemons et al. 1990). Furthermore, under normal environmental conditions, $U_3O_8$ has no significant hazardous chemical properties (Lemons et al. 1990). A literature search conducted by Martin Marietta indicated that studies documented in foreign countries support the conclusion that $U_3O_8$ is the preferred form for long-term disposition (Lemons et al. 1990).

Currently, the waste acceptance requirements at disposal sites such as DOE's Hanford site and the Envirocare site would necessitate further "stabilization" of $U_3O_8$ for disposal to reduce friability and leaching concerns. Such stabilization could generally be accomplished by encapsulating the $U_3O_8$ in a cement or polymer. INEL proposed producing a stabilized uranium oxide "rock" which could be disposed of directly at the sites which require

[1]See Information Packages 1 and 2 for a discussion of conversion processes.

stabilization (INEL 1994). The NRC, Office of Nuclear Material Safety and Safeguards, submitted a recommendation that conversion to $U_3O_8$ and placement of this material in a mined cavity be included as a long-term management option (NRC 1995). These recommendations are discussed further in Section 1.1.

## 1.1 Disposal Alternatives

The most recent analysis of depleted uranium disposal alternatives was developed as part of the decontamination and decommissioning discussions of the Louisiana Enrichment Services *Claiborne Enrichment Center (CEC) Environmental Impact Statement* (EIS) by the NRC (NRC 1994). The NRC assumed that the tails material from that operation could be disposed of in deep geological disposal units, such as an abandoned mine, or in near-surface disposal units. Technologies applicable to near-surface disposal include lined trenches, above- and below-grade vaults, and tumuli (earth-mounded bunkers). The NRC concluded that,

> It should be noted that the estimated doses [from a near-surface disposal facility] are significantly above the limits specified in 10 CFR Part 61,.... Because for near-surface disposal of $U_3O_8$, projected doses exceed 10 CFR Part 61 limits, a deep disposal site is most likely to be selected for ultimate disposition of depleted uranium. (NRC 1994).

Near-surface disposal may be a viable option if an arid disposal site remote from population centers is used, or actual waste form performance is considered. These considerations were not included in the CEC EIS (SAIC 1994).

### 1.1.1 Near-Surface Disposal

Currently, there are two DOE disposal facilities and one commercial facility which might be considered as potential candidates for near-surface disposal of low-level waste (LLW). Disposal of $U_3O_8$ at any of these sites would generally require an encapsulating agent, such as cement or polymer, typically between 50% and 70% loading of $U_3O_8$, to address friability and reduce leaching. However, encapsulation would increase the disposal volume by anywhere from 40% to 100% (SAIC 1994). Brief descriptions of these facilities are provided below.

*Nevada Test Site*

The Nevada Test Site (NTS) is a DOE facility comprising of about 1,350 square miles of federally-owned land which served as a proving ground for the testing and development of nuclear weapons. Today, NTS is a major disposal facility, primarily for LLW generated by installations within the DOE complex. Disposal of $U_3O_8$ would likely take place in dedicated

trenches and craters within the facility. Waste must be packaged in either 4x7x4-ft boxes, 4x7x2-ft boxes, or 55-gal drums, unless otherwise approved by DOE/Nevada Field Office (Hertzler 1994). Pressing or other means of agglomeration of the oxide particles could avoid the need to encapsulate the $U_3O_8$ at this site (SAIC 1994).

*Hanford Site*

The second DOE facility, the Hanford site, is located on 600 square miles of federally-owned land in Washington state. Westinghouse Hanford Company manages the Hanford site radioactive solid waste disposal facilities for the DOE/Richland Operations Office. Hanford requires all LLW to be packaged in DOE specification 17H or 17C steel 55-gal drums, unless otherwise approved by DOE/Richland (Hertzler 1994).

*Envirocare Site*

This commercial site located in Utah has a license from the Utah Department of Environmental Quality, Division of Radiation Control, which specifies a maximum concentration of 110,000 pCi/g in depleted uranium for disposal. This level could be met if the $U_3O_8$ loading were approximately 35% by volume in cement, instead of the typical encapsulation value stated above. Additionally, the Envirocare waste acceptance criteria do allow the inclusion of fill (i.e., between the drums) and separating layers in the loading calculation. Therefore, an acceptable loading of $U_3O_8$ might approach 40-45% in actual practice. Another alternative could be the disposal of $U_3O_8$ in a Ducrete form, as the higher density of Ducrete might allow the Envirocare maximum concentration to be met without any changes to the normal loadings of the cementatious waste forms and without using additional concrete (SAIC 1994).[2]

*Other Commercial Sites*

Other disposal sites may become available in the future. Tennessee is part of the Southeast Compact and has plans for a replacement to the Barnwell disposal facility in South Carolina. This facility has not been sited, but will presumably be a near-surface disposal design located in North Carolina. Both Ohio (as part of the Midwest Compact) and Kentucky (as part of the Central Midwest Compact) are also planning near-surface disposal facilities. It is unlikely that any of these facilities will be operating prior to the year 2000, and the DOE depleted uranium inventory has not been included in their projected waste volumes. Although disposal of LLW at disposal sites outside the generator's compact is not prohibited, the potential receiving compact is not obligated to accept out-of-compact LLW and can add significant surcharges to

[2]For further information on the production of Ducrete using $U_3O_8$ and/or uranium dioxide ($UO_2$), see Information Packages B1 and B2.

these wastes. For example, while it was accepting wastes, the Barnwell disposal site added a surcharge to states within the Southeast Compact other than South Carolina of $34/ft^3$, and a $220/ft^3$ surcharge for states outside the compact. This significantly increased the cost of disposal at the site from around $100/ft^3$ to approximately $300/ft^3$ (SAIC 1994).

### 1.1.2 Deep Geological Disposal

The deep geological disposal unit is assumed to be either a pre-existing cavity, such as an abandoned mine, or a facility engineered for disposal.

No deep disposal sites currently exist. The EIS for the Claiborne Enrichment Plant analyzed two geological structures for a potential deep disposal site. The first was a granite formation overlain by a thin layer of glacial till, in which emplacement was assumed to be approximately 290 m. The second was a sequence of imbedded sandstone and basalt layers, at an emplacement depth of about 635 m (NRC 1994).

### 1.1.3 Retrievable Disposal

Since depleted uranium may have some future use, it may be worthwhile to dispose of this material in a manner which allows retrieval in the future, yet meets long-term disposal criteria should the material never be retrieved. Some options include below-grade vaults, burial in concrete overpacks, and drummed depleted uranium burial at NTS in below-grade trenches/craters. To date, no studies have been done on these alternatives to determine their feasibility and economy (Hertzler 1994).

DOE Low-Level Waste Programs performed several studies in the late 1980s on waste disposal alternatives. The Above-Grade Earth-Mounded Concrete Vault (AGEMCV) was found to have the most favorable characteristics (Hertzler 1994). The AGEMCV concept consists of a waste treatment facility (WTF) and individual cement disposal vaults. When the waste is delivered from the generators, it is processed in the WTF for volume reduction, then solidified as grouted inorganics for disposal in the vaults. As each vault fills, an impervious membrane is placed in the waste stack and a concrete roof is poured on top. The final closure of the vault is a multi-layered earthen cover specifically designed to prevent water infiltration, erosion, or inadvertent intruder penetration. The solidified LLW stored within supports the roof slab, while the overlying earthen cap prevents the future subsidence and water infiltration typically associated with non-treated waste burial (Shuman et al. 1989).

To use such a design for a retrievable disposal facility, some features would have to be changed. For example, the $U_3O_8$ would not be processed or solidified, so that it would remain in a reusable form for future use. This could undermine the support of the roof slab.

Furthermore, the void volume from disposal of $U_3O_8$ in drums or containers might allow subsidence and water infiltration and leaching beyond that analyzed for LLW. To determine the performance of an AGEMCV retrievable disposal facility, additional investigation and assessments would be required (Hertzler 1994).

## *EVALUATION FACTORS*

## A. ENVIRONMENT, SAFETY, AND HEALTH

Environmental, safety, and health issues favor an oxide as the form for long-term storage or disposal of depleted uranium (Lemons et al. 1990, SAIC 1994). The primary environmental, safety, and health considerations associated with the disposal of $U_3O_8$ result from the conversion of $UF_6$ to $U_3O_8$ (NRC 1995).[3]

### A.1 Operations, Transportation, Handling, Storage, and Disposal

Depleted uranium is considered a source material under the Atomic Energy Act, and is therefore exempt from Resource Conservation and Recovery Act (RCRA) requirements for solid wastes, regardless of its chemical form (Hertzler 1994, Lemons et al. 1990). However, it is unclear how long this exemption will continue. Should the depleted $UF_6$ become subject to RCRA regulations, processing costs could potentially increase, although disposal costs of $U_3O_8$ should remain unaffected (Hertzler 1994).

The NRC and DOE classify depleted uranium as a low-level waste (LLW) due to the radioactive nature of this material, regardless of its chemical form (Hertzler 1994). Therefore, disposal of this material would have to meet the requirements of DOE Orders and/or NRC regulations for LLW (Hertzler 1994). In addition, packing and transportation of the $U_3O_8$ material would have to meet the requirements of all DOE, NRC, and DOT regulations.

The environmental, safety, and health considerations associated with disposal are related to releases to the groundwater. $U_3O_8$ is one of the most inert chemical forms of uranium, with relatively low chemical reactivity, solubility, and risks, compared to other forms of uranium. Under normal environmental conditions, $U_3O_8$ is insoluble even in the weak acids and bases typically found in soils and groundwater (Lemons et al. 1990).

*Near-Surface Disposal*

This disposal method is well developed and the environmental, safety, and health issues are well understood. The EIS for the Claiborne Enrichment Plant assumed disposal at a humid southeastern U.S. site and found doses for drinking water and agriculture to be 570 mrem/year and 31 mrem/year, respectively. These doses exceed the 10 CFR Part 61 radiological dose limits. Exposure pathways were assumed to be drinking shallow well water and consuming

[3]See information packages 1 and 2 for discussions of environmental, health and safety concerns associated with the conversion processes.

crops irrigated with shallow well water (NRC 1994). However, the assumptions of this analysis were very conservative. For example, the effects of a binding agent (i.e., cement) and arid conditions (e.g., disposal sites in the West) were not evaluated.

*Deep Geological Disposal*

The EIS for the Claiborne Enrichment Plant found doses for deep disposal in a pre-existing site to be approximately 0.016 mrem/year for drinking water and 0.23 mrem/year for agriculture within the granite formation, which fall within the 10 CFR Part 61 dose limits. The evaluation included undisturbed performance and deep well water exposure scenarios (NRC 1994). However, the analysis assumes a lower solubility for deep geological disposal than for near-surface disposal. Additionally, this analysis did not address the chemical toxicity of uranium, which could present the same hazard for deep geological disposal as for near-surface (SAIC 1994).

*Retrievable Disposal*

A 1989 radiological assessment of the AGEMCV concluded that the concrete vault would last 5,000 years and the solidified waste form would not begin to deteriorate until then (SAIC 1994). However, as discussed above, the changes to the design needed to make $U_3O_8$ retrievable could undermine the integrity of the AGEMCV to some extent, although the effects are not clear without further analysis.

## A.2 Siting Factors

Siting of a new facility would fall under either NRC standards or the Low-Level Waste Policy Act (LLWPA). It should be noted that no facilities have been sited under the LLWPA.

## A.3 Public and Worker Safety

The radiological hazards associated with depleted uranium, regardless of form, are primarily due to alpha particle emission, meaning the uranium would have to be ingested or inhaled to present a health hazard. External radiation hazards associated with $U_3O_8$ disposal are generally not a major concern. Historically, the chemical toxicity of uranium has been the primary concern for occupational exposure to depleted uranium, for which Occupational Safety and Health Administration (OSHA) standards exist (Hertzler 1994).

## B. WASTE MANAGEMENT

No additional hazardous or radioactive wastes are produced as a result of disposal of $U_3O_8$. Wastes would be generated as a result of the conversion from $UF_6$ to $U_3O_8$.[4]

## C. COST

### C.1 Disposal Costs

Costs associated with the conversion of the whole inventory of $UF_6$ to $U_3O_8$, estimated at approximately $3.0 billion, are the most significant costs associated with this disposal option (Hertzler 1994).[5] Martin Marietta estimated a unit cost of $8.40/kgU for disposing of depleted uranium. This included conversion to $U_3O_8$, disposal containers, transportation, environmental and safety documentation, and direct burial (Lemons et al. 1990).

The cost estimates presented in Table 1 were developed for INEL as part of a study of disposal options for depleted uranium. These estimates are presented in 1993 dollars, on a total cost basis as well as a per unit basis (dollars per kg U). Costs could change drastically due to unpredictable events, such as revised rate structures at the disposal facilities (Hertzler 1994).

*Table 1. Costs for $U_3O_8$ Disposal Options*

| Site | Design Construction | Packaging | Transportation | Disposal | Environmental Compliance * | Total |
|---|---|---|---|---|---|---|
| *Shallow Land Burial* | | | | | | |
| NTS | — | $40.9 M | $65.2 M | $55.7 M | $9.0 M | $170.8 M |
| | — | $0.11/kg U | $0.18/kg U | $0.15/kg U | $0.02/kg U | $0.46/kg U |
| Hanford | — | $81.8 M | $135.5 M | $654.0 M | $9.0 M | $658.0 M |
| | — | $0.23/kg U | $0.38/kg U | $1.81/kg U | $0.02/kg U | $2.44/kg U |
| *Retrievable Disposal (AGEMCV)* | | | | | | |
| NTS | $255.5 M | $111.5 M | $121.8 M | $160.2 M | $9.0 M | $658.0 M |
| | | | | | | $10.25/kg |

Source: Hertzler 1994.
Note: * - Does not include costs for RCRA compliance as $U_3O_8$ is not a RCRA-regulated waste.

[4]See Information Packages 1 and 2 for discussion of wastes generated in conversion processes.

[5]See Information Packages 1 and 2 for a discussion of the specific costs associated with the conversion processes.

NTS offers the lowest potential disposal costs, primarily due to the volume of waste handled and the fact that NTS does not fully recover disposal costs. However, NTS's rates are likely to increase dramatically in the near future due to more stringent disposal requirements, cost recovery requirements, and litigation with the state of Nevada (Hertzler 1994, SAIC 1994).

Costs of packaging and disposing of encapsulated $U_3O_8$ at Envirocare are estimated at about $572 million. This estimate does not include conversion, transportation, or environmental compliance costs (SAIC 1994).

## D. TECHNICAL MATURITY

Near-surface disposal is currently a standard industrial practice. However, deep geological disposal and retrievable disposal are in the conceptual stages and would require full development before being put into practice.

## E. SOCIOECONOMICS

### E.1 Employment

No employment data for disposal of $U_3O_8$ is available at this time.

### E.2 Public Acceptance

No evaluation of public acceptance has been made at this time. However, public concern currently exists over the storage of depleted uranium in the form of $UF_6$ at the gaseous diffusion plants. There may be significant public interest in the siting of a new disposal facility if this alternative were to be pursued. Additionally, there is often a public concern when large quantities of radioactive material are transported to disposal sites, within both the communities en route and those on the receiving end.

### E.3 Local/Regional Development

No data on local and regional development for disposal of $U_3O_8$ is available at this time.

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[6]Request for Recommendation #4

[7]Request for Recommendation #14

# INFORMATION PACKAGE
# A2

# Disposal of Depleted Uranium Metal

This information package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on depleted $UF_6$ technologies or applications currently under consideration by the Department. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; they are intended to provide sufficient information to assist the Independent Technical Reviewer.

# *DISPOSAL OF DEPLETED URANIUM METAL*

## 1. OVERVIEW

This information package briefly describes disposal of depleted uranium (DU) metal. It also provides supplemental data on environment, safety and health; waste management; cost; technical maturity; and socioeconomics, to assist in the evaluation of Request for Recommendation (RFR) submittals from GenCorp Aerojet (RFR No. 15) and from Dr. Velma M. Shearer (RFR No. 19).

This information package discusses the disposal of DU metal after it has been converted from depleted uranium hexafluoride ($UF_6$).[1] The Nuclear Regulatory Commission (NRC) categorizes depleted uranium as a low-level waste (LLW). Potential disposal options for LLW are near-surface, deep geological, or retrievable disposal.

As a disposal form, DU metal has several advantages. It is virtually insoluble in water (Lemons et al. 1990) and is the most volumetrically efficient form because its high density significantly reduces the volume of material (Hertzler 1994). Furthermore, commercial conversion facilities currently exist for processing $UF_6$ into metal.

However, DU metal has some drawbacks as a disposal form. Uranium metal readily undergoes surface oxidation due to reaction with air and moisture, forming a pyrophoric surface (Lemons et al. 1990). To prevent or minimize this oxidation, a protective coating could be applied to the DU metal (Lemons et al. 1990). DU metal will also react with water at ambient temperature, forming uranium dioxide ($UO_2$) and uranium hydride ($UH_3$). The metal swells and disintegrates, and can release a hydrogen gas (Lemons et al. 1990). This reactivity and poor corrosion resistance may limit metal disposal unless it is encapsulated in a corrosion-resistant package (e.g., the Multi-Purpose Container) (SAIC 1994).

### 1.1 Permanent Disposal Alternatives

The most recent analysis of depleted uranium disposal alternatives were developed as part of decontamination and decommissioning discussions in the Environmental Impact Statement (EIS) from the Louisiana Enrichment Services, Claiborne Enrichment Center (CEC), by the NRC (NRC 1994). The NRC considered depleted uranium to be a Class A low-level radioactive waste and determined that triuranium octaoxide ($U_3O_8$) has the best potential long-

[1]See Information Packages 3, 4, and 5 for a discussion of the conversion processes.

long-term stability in a geological disposal environment. The NRC further determined that a deep geological disposal site would meet the limits specified in 10 CFR Part 61 (*Disposal of High-Level Radioactive Wastes in Geologic Repositories*) and would most likely be selected for ultimate disposition of depleted uranium (NRC 1994). However, near-surface disposal could be a viable option if an arid disposal site remote from population centers were assumed, or actual waste form performance were considered. These considerations were not included in the CEC EIS (SAIC 1994).

Permanent disposal of DU metal would involve emplacement either in deep geological disposal units, such as an abandoned mine, or in near-surface disposal units. Technologies applicable to near-surface disposal include lined trenches, above- and below-grade vaults, and tumuli (earth-mounded bunkers). The regulatory aspects of DU metal disposal are more ambiguous than for uranium oxides; however, the U. S. Army has previously disposed of relatively small quantities of bulk DU metal (from its military programs) at the Nevada Test Site (Hertzler 1994). Based on this precedent, it is assumed that bulk DU metal could be an acceptable waste form for disposal. Conversion of the existing inventory of 560,000 metric tons of depleted $UF_6$ would yield about 19,900 $m^3$ or 703,000 $ft^3$ of DU metal (SAIC 1994). Current regulations and site waste acceptance criteria do not allow such large-scale disposal of DU metal at any of the existing disposal sites (SAIC 1994).

### 1.1.1 Near-Surface Disposal

Currently, there are one commercial and two Department of Energy (DOE) disposal facilities which are potential candidates for near-surface disposal of LLW. Brief descriptions of these facilities are provided below.

*Nevada Test Site*

The Nevada Test Site (NTS) is a DOE facility comprising about 1,350 square miles of federally-owned land which served as a proving ground for the testing and development of nuclear weapons. Today, NTS includes a major disposal facility, primarily for LLW generated by installations within the DOE complex. Waste must be packaged in either 4x7x4-ft boxes, 4x7x2-ft boxes, or 55-gal drums, unless otherwise approved by DOE/Nevada Field Office (Hertzler 1994). Encapsulation of DU metal would not be required to meet the waste acceptance criteria (WAC) of this site.

*Hanford Site*

The second DOE disposal facility, the Hanford Site, is located on 600 square miles of federally-owned land in Washington State. Hanford requires all LLW to be packaged in DOE specification 17H or 17C steel 55-gal drums, unless otherwise approved by

DOE/Richland (Hertzler 1994). The current WAC for the Hanford site would require encapsulation of DU metal.

*Envirocare Site*

Envirocare is a commercial site which is located in Utah and has a license from the Utah Department of Environmental Quality, Division of Radiation Control. The Envirocare WAC specify a maximum concentration of 110,000 pCi/g in depleted uranium for disposal (Hertzler 1994). Due to the concentration of depleted uranium in the metal, the disposal cell would require adjustments (e.g., dilution in an encapsulating media, or commingling with other LLW) to meet this concentration requirement.

*Other Commercial Sites*

Other disposal sites may become available in the future. Tennessee is part of the Southeast Compact and has plans to replace the Barnwell disposal facility in South Carolina. This facility has not been sited, but will presumably be a near-surface disposal unit located in North Carolina. Both Ohio (as part of the Midwest Compact) and Kentucky (as part of the Central Midwest Compact) are also planning near-surface disposal facilities. As these are humid sites, encapsulation of DU metal would probably be required. It is unlikely that any of these facilities will be operating prior to the year 2000, and the DOE depleted uranium inventory has not been included in their projected waste volumes. Although disposal of LLW at sites outside the generator's Compact is not prohibited, the potential receiving Compact is not obligated to accept out-of-Compact LLW and can add significant surcharges to these wastes. For example, while it was accepting wastes, the Barnwell disposal site added a $\$34/ft^3$ surcharge to states within the Southeast Compact other than South Carolina, and a $\$220/ft^3$ surcharge for states outside the Compact. This significantly increased the cost of disposal at the site from around $\$100/ft^3$ to approximately $\$300/ft^3$ (SAIC 1994).

### 1.1.2 Deep Geological Disposal

The deep geological disposal unit is assumed to be either a pre-existing cavity, such as an abandoned mine, or a facility engineered for disposal.

No deep disposal sites currently exist. The CEC EIS analyzed two hypothetical geological structures for deep disposal of $U_3O_8$. The first was a granite formation overlain by a thin layer of glacial till. The second was a sequence of imbedded sandstone and basalt layers. Emplacement of the $U_3O_8$ at a depth of 290 m (0.18 miles) and 635 m (0.39 miles) was assumed in the granite formation and the sandstone/basalt layers, respectively. The NRC analysis concluded that deep geological disposal of $U_3O_8$ would meet dose limit requirements (NRC 1994).

of glacial till. The second was a sequence of imbedded sandstone and basalt layers. Emplacement of the $U_3O_8$ at a depth of 290 m (0.18 miles) and 635 m (0.39 miles) was assumed in the granite formation and the sandstone/basalt layers, respectively. The NRC analysis concluded that deep geological disposal of $U_3O_8$ would meet dose limit requirements (NRC 1994).

## 1.2 Retrievable Disposal

Since DU metal may have some future use,[2] it may be worthwhile to dispose of this material in a manner which allows retrieval in the future, yet meets long-term disposal criteria should the material never be retrieved. A near-surface site would likely be the most economical facility for retrievable disposal. Some options include below-grade vaults, burial in concrete overpacks, and drummed depleted uranium burial at NTS in below-grade trenches/craters. To date, no studies have been done on these alternatives to determine their feasibility and economy (Hertzler 1994); however, other waste disposal options may be applicable to retrievable disposal of DU metal.

DOE Low Level Waste Programs performed several studies in the late 1980s on waste disposal alternatives. The Above-grade Earth-Mounded Concrete Vault (AGEMCV) was found to have the most favorable characteristics (Hertzler 1994). The AGEMCV concept consists of a waste treatment facility (WTF) and individual cement disposal vaults. When the waste is delivered from the generators, it is processed in the WTF for volume reduction, then solidified as grouted inorganics for disposal in the vaults. As each vault fills, an impervious membrane is placed in the waste stack and a concrete roof is poured on top. The final closure of the vault is a multi-layered earthen cover specifically designed to prevent water infiltration, erosion, or inadvertent intruder penetration. The solidified LLW stored within supports the roof slab, while the overlying earthen cap prevents the future subsidence and water infiltration typically associated with non-treated waste burial (Shuman et al. 1989).

Using such a design for a retrievable disposal facility for DU metal is possible. The DU metal could be cast or otherwise worked to form the disposal packages envisioned in the AGEMCV studies. However, the surface oxidation and poor corrosion resistance of the DU metal could become a concern. If the DU metal requires corrosion-resistant packages for disposal, any resulting void volume might allow subsidence and water infiltration and leaching beyond that analyzed for LLW. To determine the performance of an AGEMCV retrievable disposal facility, additional investigation and assessments would be required (Hertzler 1994).

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[2]See Information Packages E1, H1, I1, and J1 for discussions of the potential uses of DU metal.

## *EVALUATION FACTORS*

## A. ENVIRONMENT, SAFETY, AND HEALTH

Some of the environmental, safety, and health considerations associated with the disposal of DU metal result from the conversion of $UF_6$ to DU metal (SAIC 1994).[3]

### A.1 Operations, Transportation, Handling, Storage, and Disposal

Depleted uranium is considered a source material under the Atomic Energy Act, and is therefore exempt from Resource Conservation and Recovery Act (RCRA) requirements for solid wastes, regardless of its chemical form (Hertzler 1994; Lemons et al. 1990). If DU metal became subject to RCRA regulations, disposal costs could potentially increase (Hertzler 1994).

The NRC and DOE classify depleted uranium as a low-level waste (LLW) due to its radioactive nature (Hertzler 1994). Disposal of DU metal would have to meet the requirements of DOE Orders and/or NRC regulations for LLW as well as the WAC of the particular disposal site (Hertzler 1994). In addition, packaging and transportation of the DU metal would have to meet the requirements of all DOE Orders and NRC and DOT regulations. Current regulations and WACs do not allow such large-scale disposal of DU metal at any of the disposal sites described in Section 1.1.1, and encapsulation of some type would probably be required (SAIC 1994).

The environmental, safety, and health considerations associated with disposal are mainly related to releases to the groundwater. DU metal will react with water at ambient temperatures to form $UO_2$ and $UH_3$ (Lemons et. al. 1990); therefore, some protective actions, such as a coating on the metal (Lemons et al. 1990) or a corrosion-resistant container (SAIC 1994), would be required to ensure that the DU metal surface did not react with the air and moisture.

### A.2 Siting Factors

Siting of a new facility would be regulated either by NRC standards or by the Low-Level Waste Policy Act (LLWPA). It should be noted that no new LLW disposal facilities have been sited under the LLWPA.

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[3]See information packages 3, 4, and 5 for discussions of Environmental, Health and Safety concerns associated with the conversion processes.

### A.3 Public and Worker Safety

The radiological hazards associated with depleted uranium, regardless of form, are primarily due to alpha particle emission, meaning that the uranium would have to be ingested or inhaled to present a health hazard. External radiation hazards associated with DU metal disposal are generally not a major concern. Historically, the chemical toxicity of uranium has been the primary concern related to occupational exposure to depleted uranium, for which Occupational, Safety and Health Administration (OSHA) standards exist (Hertzler 1994).

## B. WASTE MANAGEMENT

No additional hazardous or radioactive wastes are produced as a result of the disposal of DU metal. Wastes would be generated as a result of the conversion from $UF_6$ to DU metal.[4]

## C. COST

Table 1, row 1, shows estimated costs (in millions) for shallow land burial of the entire 560,000 metric ton depleted urainum inventory as DU metal at NTS, based on a precedent established by the U.S. Army (Hertzler 1994). Row 2 breaks down the costs by kilogram of uranium. No cost estimates exist for deep geological or retrievable disposal.

*Table 1. Estimated Costs for Shallow Land Burial of DU Metal at NTS*

| *Packaging* | *Transportation* | *Disposal* | *Environmental Compliance* | *Total* |
|---|---|---|---|---|
| $46.7 M<br>$0.13/kg U | $56.1 M<br>$0.16/kg U | $15.4 M<br>$0.04/kg U | $9.0 M<br>$0.02/kg U | $127.2 M<br>$0.35/kg U |

Source: Hertzler 1994.

NTS rates are likely to increase dramatically in the near future due to increasingly stringent disposal requirements, cost recovery requirements, and litigation with the state of Nevada (Hertzler 1994; SAIC 1994).

Costs associated with the conversion of the whole inventory of $UF_6$ to DU metal, estimated at approximately $3.6 billion ($10/kgU), are the most significant costs associated with this disposal option (Hertzler 1994). These costs do not take account of the cost of waste disposal

[4]See Information Packages 3, 4, and 5 for a discussion of the wastes generated in the conversion processes.

or the resale of the secondary waste materials (i.e., $MgF_2$, HF) resulting from this conversion.[5]

## D. TECHNICAL MATURITY

Near-surface disposal is currently a standard industrial practice. However, deep mine (geological) disposal and retrievable disposal are in the conceptual stages and would require full development before being put into practice.

## E. SOCIOECONOMICS

### E.1 Employment

No employment data for disposal of DU metal is available at this time.

### E.2 Public Acceptance

No evaluation of public acceptance has been made at this time.

### E.3 Local/Regional Development

No data on local and regional development for disposal of DU metal is available at this time.

[5]See Information Packages 3, 4, and 5 for a discussion of the conversion costs and waste disposal costs associated with the conversion processes.

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[6]Request for Recommendation #15.

[7]Request for Recommendation #19.

# INFORMATION PACKAGE
# A3
# Disposal of $UO_2$

This information package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on depleted $UF_6$ technologies or applications currently under consideration by the Department. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; they are intended to provide sufficient information to assist the Independent Technical Reviewer.

# *DISPOSAL OF $UO_2$*

## 1. OVERVIEW

This information package describes disposal of depleted uranium in the form of uranium dioxide ($UO_2$). It also provides supplemental data on environment, safety, and health; waste management; cost; technical maturity; and socioeconomics, to assist in the evaluation of Request for Recommendation submittal #4 from Idaho National Engineering Laboratory (INEL).

The Nuclear Regulatory Commission (NRC) categorizes depleted uranium as a low-level waste (LLW). Potential disposal options for the depleted uranium inventory are near-surface, deep geological, or retrievable disposal. Due to the reactive nature of uranium hexafluoride ($UF_6$), it would need to be converted to another form prior to disposal, and uranium oxides have been proposed for the disposal form (NRC 1994). This information package discusses the disposal of $UO_2$[1] after it has been converted from depleted uranium hexafluoride.

With respect to the radiological and chemical characteristics of depleted uranium and the potential impact on people and the environment, the choice of chemical form for disposal is based on three considerations (Hertzler 1994):

(1) potential release (i.e., solubility and dispersibility),
(2) environmental behavior (i.e., reactivity and solubility),
(3) relative toxicity in drinking water.

With no additional treatment after conversion, $UO_2$ is chemically stable and has a melting point of 2878°C (Hertzler 1994). $UO_2$ will slowly convert to $U_3O_8$ in air at ambient temperature unless it is stabilized by sintering or other means (Hertzler 1994). Aside from being considerably denser, $UO_2$ has similar properties to $U_3O_8$.

### 1.1 Permanent Disposal Alternatives

The waste acceptance criteria (WAC) for most disposal sites would require encapsulating $UO_2$ in concrete or in a polymer to meet regulatory requirements, resulting in increased disposal volume. INEL proposes using the sintered $UO_2$ pellets for disposal. Sintering reduces pore volumes, resulting in higher densities (90-95% of theoretical) and lower total disposal volumes (by about

[1] See Information Packages 6/7/8 and 9 for a discussion of the conversion processes.

60%) (INEL 1994). Additionally, if this form does not meet the waste acceptance criteria of the disposal sites, it could be further encapsulated as Ducrete (see Information Package A1). This alternative would result in a lower total disposal volume than encapsulation in standard concrete (SAIC 1994). Due to the density of $UO_2$, container design may require modification to support potentially large material weights and to meet waste acceptance criteria.

### 1.1.1 Near-Surface Disposal

The NRC *Claiborne Enrichment Center Environmental Impact Statement* (EIS) evaluated near-surface disposal of depleted uranium oxide $U_3O_8$ at a humid southern location. The performance assessment indicated that dose limit requirements would be exceeded (NRC 1994). However, near-surface disposal could be a viable option if less conservative assumptions were made. Disposal of encapsulated oxide at an arid western site may meet dose limit requirements (SAIC 1994). Currently, there are two Department of Energy facilities (DOE) and one commercial disposal facility which might be considered as potential candidates for near-surface disposal of low-level waste (LLW). Brief descriptions of these facilities are provided below.

#### *Nevada Test Site*

The Nevada Test Site (NTS) is a DOE facility comprising of about 1,350 square miles of federally-owned land which served as a proving ground for the testing and development of nuclear weapons. Today, NTS includes a major disposal facility primarily for LLW generated by installations within the DOE complex. Disposal of $UO_2$ would likely take place in dedicated trenches and craters within the facility. Waste must be packaged in either 4x7x4-foot boxes, 4x7x2-foot boxes, or 55-gal drums, unless otherwise approved by DOE/Nevada Field Office (Hertzler 1994). For $UO_2$ pellets and large particles, no encapsulation should be necessary to meet the NTS WAC (SAIC 1994). For fine particles and powders, encapsulation would be required (SAIC 1994).

#### *Hanford Site*

The second DOE disposal facility, the Hanford Site, is located on 600 square miles of federally-owned land in Washington state. Hanford requires all LLW to be packaged in DOT specification 17H or 17C steel 55-gal drums, unless otherwise approved by DOE/Richland (Hertzler 1994). Hanford would require encapsulation of $DUO_2$ in cement regardless of the physical form.

*Envirocare Site*

This commercial site located in Utah has a license from the Utah Department of Environmental Quality, Division of Radiation Control, which specifies a maximum concentration of 110,000 pCi/g in depleted uranium for disposal. This would correspond to a $DUO_2$ fraction in the concrete of approximately 30%. Additionally, the Envirocare waste acceptance criteria do allow the inclusion of fill (i.e., between the drums) and separating layers in the loading calculation. Encapsulation is not required, but allows the limits to be met.

*Other Commercial Sites*

Other disposal sites may become available in the future. Tennessee is part of the Southeast Compact and has plans for to replace to the Barnwell disposal facility in South Carolina. This facility has not been sited, but will presumably be a near-surface disposal design located in North Carolina. Both Ohio (as part of the Midwest Compact) and Kentucky (as part of the Central Midwest Compact) are also planning near-surface disposal facilities. These are humid sites and will probably require encapsulation. It is unlikely that any of these facilities will be operating prior to the year 2000, and the DOE depleted uranium inventory has not been included in their projected waste volumes. Although disposal of LLW at disposal sites outside the generator's Compact is not prohibited, the potential receiver is not obligated to accept out-of-Compact LLW and can add significant surcharges to these wastes. For example, while it was accepting wastes, the Barnwell disposal site added a surcharge of $\$34/foot^3$ for states other than South Carolina within the Southeast Compact other and a $\$220/foot^3$ surcharge for states outside the compact. This significantly increased the cost of disposal at the site from around $\$100/foot^3$ to approximately $\$300/foot^3$ (SAIC 1994).

### 1.1.2 Deep Geological Disposal

The deep geological disposal unit is assumed to be either a pre-existing cavity, such as an abandoned mine, or a facility engineered for disposal.

No deep disposal sites currently exist. The EIS for the Claiborne Enrichment Center analyzed two hypothetical geological structures for deep disposal of $U_3O_8$. The first was a granite formation overlain by a thin layer of glacial till, in which emplacement was assumed to be approximately 290 m. The second was a sequence of imbedded sandstone and basalt layers, at an emplacement depth of about 635 m (NRC 1994). The NRC analysis concluded that deep geological disposal of $U_3O_8$ would meet dose limit requirements (NRC 1994).

## 1.2 Retrievable Disposal

Since depleted uranium may have some future use, it may be worthwhile to dispose of this material in a manner which allows retrieval in the future, yet meets long-term disposal criteria should the material never be retrieved. Some options include below-grade vaults, burial in concrete overpacks, and drummed depleted uranium burial at NTS in below-grade trenches/craters. To date, no studies have been done on these alternatives to determine their feasibility and cost effectiveness (Hertzler 1994).

DOE LLW Programs performed several studies in the late 1980s on waste disposal alternatives. The Abovegrade Earth-Mounded Concrete Vault (AGEMCV) was found to have the most favorable characteristics (Hertzler 1994). The AGEMCV concept consists of a waste treatment facility (WTF) and individual cement disposal vaults. When the waste is delivered from the generators, it is processed in the WTF for volume reduction, then solidified as grouted inorganics for disposal in the vaults. As each vault fills, an impervious membrane is placed in the waste stack and a concrete roof is poured on top. The final closure of the vault is a multi-layered earthen cover specifically designed to prevent water infiltration, erosion, or inadvertent intruder penetration. The solidified LLW stored within supports the roof slab, while the overlying earthen cap prevents the future subsidence and water infiltration typically associated with non-treated waste burial (Shuman et al. 1989).

To use such a design as a retrievable disposal facility, some features would have to be changed. For example, the $UO_2$ would not be processed or solidified so that it would remain in a reusable form. This could undermine the support of the roof slab. Furthermore, the void volume from disposal of $UO_2$ in drums or containers might allow subsidence and water infiltration and leaching beyond that analyzed for LLW. To determine the performance of an AGEMCV retrievable disposal facility, additional investigation and assessments would be required (Hertzler 1994).

## *EVALUATION FACTORS*

## A. ENVIRONMENT, SAFETY, AND HEALTH

The primary effects of depleted uranium disposal are the environmental, safety and health (ES&H) considerations associated with the conversion of $UF_6$ to $UO_2$ (NRC 1995) (see Information Packages 6/7/8 and 9 for a discussion of ES&H for conversion processes).

### A.1 Operations, Transportation, Handling, Storage, and Disposal

The NRC and DOE classify depleted uranium as a low-level waste (LLW) due to its radioactive nature (Hertzler 1994). Disposal of $UO_2$ would have to meet the requirements of DOE Orders and/or NRC regulations for LLW as well as the WAC of the disposal site (Hertzler 1994). In addition, packaging and transporting the $UO_2$ material would have to meet the requirements of all DOE Orders and NRC and DOT regulations.

The environmental, safety, and health considerations associated with disposal are primarily related to groundwater releases. $UO_2$ is one of the most inert chemical forms of uranium, with relatively low chemical reactivity, solubility, and risks compared to other forms of uranium. Under normal environmental conditions, $UO_2$ is insoluble even in the weak acids and bases typically found in soils and groundwater (Lemons, et al: 1990).

*Near-Surface Disposal*

The NRC EIS for the Claiborne Enrichment Center looked only at $U_3O_8$, which is chemically similar to $UO_2$. This EIS assumed disposal at a humid southeastern U.S. site and found doses for drinking water and agriculture to be 570 mrem/year and 31 mrem/year, respectively. These doses exceed the 25 mrem/year 10 CFR Part 61 (*Licensing Requirements for Land Disposal of Radioactive Waste*) radiological dose limits. Exposure pathways were assumed to be drinking shallow well water and consuming crops irrigated with shallow well water (NRC 1994). An arid western disposal site was not analyzed (NRC 1994). Sintered ceramic $UO_2$ should perform better than $U_3O_8$; however, this form was not analyzed (NRC 1994).

*Deep Geological Disposal*

Based upon $U_3O_8$, the EIS for the Claiborne Enrichment Center found doses for deep disposal in a pre-existing site of approximately 0.016 mrem/year for drinking water and 0.23 mrem/year for agriculture within the granite formation, which fall within the 10 CFR Part 61 dose limits. The evaluation included undisturbed performance and deep well water exposure scenarios

(NRC 1994). However, the analysis assumes a lower solubility for deep geological disposal than for near-surface disposal. Additionally, this analysis did not address the chemical toxicity of uranium, which could present the same hazard for deep geological disposal as for near-surface (SAIC 1994).

*Retrievable Disposal*

A 1989 radiological assessment of the Abovegrade Earth-Mounded Concrete Vault (AGEMCV) concluded that the concrete vault would last 5,000 years and the solidified waste form would not begin to deteriorate until then (SAIC 1994). However, as discussed earlier, design changes needed to make $UO_2$ retrievable in the future would undermine the integrity of the AGEMCV to some extent, although the effects are not clear without further analysis.

A.2 Siting Factors

Siting of a new facility would be regulated by NRC standards or by the LLW Policy Act (LLWPA). It should be noted that no new LLW disposal facilities have been sited or operated under the LLWPA.

A.3 Public and Worker Safety

The radiological hazards associated with depleted uranium, regardless of form, are primarily due to alpha particle emission, meaning that the uranium would have to be ingested or inhaled to present a health hazard. External radiation hazards associated with $UO_2$ disposal are generally not a major concern (Hertzler 1994). Historically, the chemical toxicity of uranium has been the primary concern for occupational exposure to depleted uranium, for which Occupational Safety and Health Administration (OSHA) standards exist (Hertzler 1994).

## B. WASTE MANAGEMENT

No additional known hazardous or radioactive wastes are produced as a result of disposal of $UO_2$.

## C. COST

### C.1 Disposal Costs

Most of the estimates have centered on the disposal of $U_3O_8$ rather than $UO_2$. Costs associated with the conversion of the whole inventory of $UF_6$ to $U_3O_8$, estimated at approximately $3.0 billion, are the most significant costs associated with this disposal option (Hertzler 1994). Martin Marietta estimated a unit cost for disposing of depleted uranium of $8.40/kgU. This included conversion to $U_3O_8$, disposal containers, transportation, environmental and safety documentation, and direct burial (Lemons et al. 1990).

Table 1 presents disposal cost estimates for $U_3O_8$ that were developed for INEL as part of a study of disposal options for depleted uranium. These estimates are presented in 1993 dollars, on a total cost basis as well as a per unit basis (dollars per kgU). Costs could change drastically due to unpredictable events, such as revised rate structures at the disposal facilities (Hertzler 1994). Costs for $UO_2$ were not discussed.

***Table 1. Costs for Disposal Options for $U_3O_8$***

| Site | Disposal Costs |
|---|---|
| *Shallow Land Burial* | |
| NTS | $55.7M |
| | $0.15/kgU |
| Hanford | $654.0 M |
| | $1.81/kgU |
| *Retrievable Disposal (AGEMCV)* | |
| NTS | $160.2 M |
| | |

(Source: Hertzler 1994)

Table 2 shows the projected disposal costs for $UO_2$. Most of the costs in Table 2 represent disposal charges ranging from $0.75 to $1.75 per kilogram of DU.

*Table 2. Parameters and Costs for Disposal of $DUO_2$ Pellets at Existing Facilities*

| Facility/ Site | Category | Disposal Volume, $Mft^3$ | Unit Disposal Charges, $/$ft^3$ | Total Disposal Cost, $M |
|---|---|---|---|---|
| NTS | DOE/Arid | 1.69<br>(2.41 with drums) | 12 | 29<br>(11)<br>40 |
| RL/Hanford | DOE/Arid | 2.54<br>(3.63 with drums) | 59 | 214<br>(17)<br>231 |
| Envirocare | Commercial/ Arid | 4.77<br>(6.81 with drums) | 40 | 272<br>(32)<br>304 |

Note 1: Standard, 17C/17H drums assumed for containerization, at $50 each, with a disposal volume loading of 70%. Container costs are shown in parentheses.
Note 2: Envirocare WAC is based upon waste emplacement, and allows the inclusion of fill material (i.e. in between the drums) in the calculation of radionuclide loadings. Hence, the waste disposal volumes may be 10-20% lower than shown in the Table.
Note 3: Cement encapsulation assumes 70% volume loading of the depleted uranium oxide in the wasteform.
Note 4: Conversion, transportation, cylinder, and by product costs are not included.
Source: SAIC 1994.

NTS offers the lowest potential disposal costs primarily due to the volume of waste handled and the fact that NTS does not fully recover disposal costs. However, NTS' rates are likely to increase dramatically in the near future due to increasingly stringent disposal requirements, cost recovery requirements, and litigation with the State of Nevada (Hertzler 1994; SAIC 1994).

## D. TECHNICAL MATURITY

Near-surface disposal is currently a standard industrial practice. However, deep geological disposal and retrievable disposal is in the conceptual stages and would require full development before putting into practice.

## E. SOCIOECONOMICS

### E.1 Employment

No employment data for disposal of $UO_2$ is available at this time.

### E.2 Public Acceptance

No evaluation of public acceptance has been made at this time. However, several of the responses to the Federal Register Notice expressed concern over the current depleted $UF_6$ storage practices at the Gaseous Diffusion Plants. Additionally, some responses indicated that there would be significant public interest in the siting of a new disposal facility if this alternative were to be pursued.

### E.3 Local/Regional Development

No data on local and regional development for disposal of $UO_2$ is available at this time.

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Request for Recommendation #4

Request for Recommendation #14

# INFORMATION PACKAGE
# B1

## Ducrete Using $U_3O_8$

This Information Package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on Depleted $UF_6$ technologies or applications currently under consideration by the Department of Energy. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; it is intended to provide sufficient information to assist the Independent Technical Reviewer.

# *DUCRETE USING $U_3O_8$*

## 1. OVERVIEW

This information package briefly describes production of and applications for Ducrete made from triuranium octoxide ($U_3O_8$). It also provides supplemental data on environment, safety, and health; waste management; cost; technical maturity; and socioeconomics to assist in the evaluation of the Request for Recommendation submittal from Idaho National Engineering Laboratory (INEL).

The Idaho National Engineering Laboratory (INEL) proposes using depleted uranium concrete (known as "Ducrete") as a shielding material for spent nuclear fuel in future storage containers, such as the multi-purpose container (MPC) being developed by the Department of Energy (DOE). This application is similar to that for Ducrete using uranium dioxide ($UO_2$).[1]

Standard concrete is a mixture of cement, sand ($SiO_2$), and aggregate (gravel, usually $SiO_2$ forms). However, by substituting a uranium oxide in the place of either the sand, the gravel, or the aggregate, a depleted uranium concrete, or Ducrete, can be produced which has a much higher density than standard concrete (Murray 1994). This package will discuss the production of and uses for Ducrete using $U_3O_8$.

### 1.1 General Information

The depleted uranium must first be converted to $U_3O_8$.[2] The conversion product is in the form of a powder which is chemically stable, with a melting point of 1300°C, at which it decomposes and converts to $UO_2$. $U_3O_8$ can be compacted and granulated into medium density materials (3-5 g/cm$^3$) that increase the density of concrete. These properties allow $U_3O_8$ to be substituted for the sand constituent of concrete.

### 1.2 Input Materials

The major input materials for the production of Ducrete using $U_3O_8$ include cement, $U_3O_8$ powder, and aggregate. The ratios of these materials are presented in Table 1 (Lessing et al.).

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[1]See Information Package B2 for a discussion of Ducrete using $UO_2$.

[2]See Information Packages 1 and 2 for a discussion of the conversion processes.

*Table 1. Ratio of Materials for Ducrete*

| Material | Quantity |
|---|---|
| Cement | 1 part |
| $U_3O_8$ powder | 2 parts |
| Aggregate | 14 - 18 parts |

The aggregate can be in the form of either gravel or $UO_2$ pellets. Testing of Ducrete made with just $U_3O_8$ powder and gravel found that it did not exhibit characteristics of strength and temperature limitations comparable to standard concrete (Lessing et al.). However, preliminary testing data have shown much more promise in Ducrete which uses $U_3O_8$ as the sand component and $UO_2$ pellets as the aggregate. Consequently, current Ducrete development has shifted away from using just $U_3O_8$.[3]

## 1.3 Depleted $UF_6$ Consumption

Ducrete could be used as shielding for storage/disposal containers for spent nuclear fuel (SNF)/high-level wastes (HLW) and as a hardened structure material for shelters or storage buildings. Additionally, Ducrete could be used as a disposal form at any of the low-level waste (LLW) disposal sites. These alternatives are further addressed below.

*Storage/Disposal Containers*

The commercial nuclear fuel container industry currently manufactures a cylindrical container used for at-reactor storage of SNF (Quapp 1994). These containers use approximately 70 cm of concrete as shielding and weigh approximately 118 MT fully loaded. Since Ducrete is denser than standard concrete, a Ducrete container would require less thickness to ensure adequate attenuation of neutron and gamma radiation, resulting in a smaller and lighter container (Quapp 1994). However, Ducrete from $UO_2$ would most likely produce the best results in these applications.

The following concepts are currently under consideration:

[3] See Information Package B2 for a discussion of Ducrete made from $UO_2$.

(1) Storage-only Vessel. Modeled after the commercial concrete container, this is an onsite concrete storage vessel with an inner metallic thin-walled canister for storing SNF prior to disposal (Haelsig 1994).

(2) Transportable Storage System. This design uses a Ducrete cask which could be loaded and sealed within the reactor fuel pool. This cask could then be either used for onsite storage or transported via a transportation overpack to a repository or into monitored retrievable storage, without opening the cask and risking worker exposure (Haelsig 1994). This is similar to the Multi-Purpose Cask concept currently being developed by DOE's Office of Civilian Radioactive Waste Management.

Given the projected removal schedule for commercial SNF through the year 2030, approximately 3,500 canisters may be required for storage and/or transport (Haelsig 1994).

*Hardened Structures*

Ducrete could be used to replace standard concrete in structures such as the NATO aircraft shelters or weapons storage bunkers. Its higher density results in greater resistance to impacts and explosions. Currently, over 4,500 shelters exist within NATO and other allied countries (Cooley 1994). Any upgrades to these existing structures or construction of new facilities could be accomplished using Ducrete. However, current plans for upgrades or new construction are not known at this time.

*Disposal*

Disposal of depleted uranium in the form of $U_3O_8$ would generally require encapsulating it in a concrete or a polymer, resulting in increases in disposal volume.[4] If this encapsulation were in Ducrete rather than in standard concrete, the total disposal volume would not increase as much, due to the higher density of Ducrete (Murray 1994).

[4]See Information Package A1 for a discussion of stabilization requirements for disposal of $U_3O_8$.

## *EVALUATION FACTORS*

## A. ENVIRONMENT, SAFETY, AND HEALTH

### A.1 Operations, Transportation, Handling, Storage, and Disposal

The primary environmental, safety, and health considerations associated with the fabrication of Ducrete result from the conversion of $UF_6$ to $U_3O_8$.[5] No unusual environmental, safety, or health concerns are anticipated in the production of Ducrete. No additional dusting and contamination concerns exist that have not been addressed by existing $UO_2$ and LLW cement encapsulation plants (Murray 1994).

### A.2 Siting Factors

Several firms currently fabricating SNF storage containers could probably adapt their operations to produce Ducrete containers. Some of these facilities are licensed by the NRC (Haelsig 1994). If another facility were required, it would also have to be licensed.

### A.3 Public and Worker Safety

The radiological hazards associated with depleted uranium, regardless of form, are primarily due to alpha particle emission, meaning that the uranium would have to be ingested or inhaled to present a health hazard. External radiation hazards associated with $U_3O_8$ handling are generally not a major concern. Historically, the chemical toxicity of uranium has been the primary concern for occupational exposure to depleted uranium, for which Occupational Health and Safety Administration (OSHA) standards exist (Hertzler 1994).

## B. WASTE MANAGEMENT

The wastes of primary concern for this alternative are generated as a result of the conversion from $UF_6$ to $U_3O_8$.[6] No hazardous or radioactive wastes are produced in the fabrication of Ducrete itself. However, once the Ducrete application is no longer required, Ducrete would have to be disposed of as a low-level radioactive waste. This leaves a degree of uncertainty as to future decommissioning and disposal cost liabilities (Haelsig 1994).

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[5] See Information Packages 1 and 2 for a discussion of the environmental, safety, and health concerns associated with the conversion processes.

[6] See Information Packages 1 and 2 for a discussion of the wastes associated with the conversion processes.

## C. COST

Although no cost estimates have been developed for the production of Ducrete from $U_3O_8$, overall production costs are expected to be higher than for standard concrete. This is primarily due to the costs associated with $U_3O_8$ conversion.[7] Ducrete production plant costs are expected to be comparable to standard cement plant costs for encapsulating LLW (Murray 1994).

## D. TECHNICAL MATURITY

Production of Ducrete has been through preliminary testing but remains undeveloped on a large scale because of unsatisfactory results. Development efforts have turned to fabrication of Ducrete from $UO_2$ pellets. DOE is pursuing the fabrication of Ducrete from $UO_2$ and has funded process development efforts in FY 1995 to assess options for large-scale, low-cost fabrication methods (INEL 1994).

## E. SOCIOECONOMICS

### E.1 Employment

No employment data for producing Ducrete from $U_3O_8$ are available at this time.

### E.2 Public Acceptance

No evaluation of public acceptance has been made at this time.

### E.3 Local/Regional Development

No data on local and regional development for producing Ducrete from $U_3O_8$ are available at this time.

[7] See Information Packages 1 and 2 for a discussion of the costs associated with the conversion processes.

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[8]Request for Recommendation #4.

# INFORMATION PACKAGE
# B2

# Ducrete Using $UO_2$

This Information Package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on Depleted $UF_6$ technologies or applications currently under consideration by the Department of Energy. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; it is intended to provide sufficient information to assist the Independent Technical Reviewer.

# *DUCRETE USING $UO_2$*

## 1. OVERVIEW

This information package briefly describes production of and applications for Ducrete made from $UO_2$. It also provides supplemental data on environment, safety, and health; waste management; cost; technical maturity; and socioeconomics to assist in the evaluation of the Request for Recommendation submittal from Idaho National Engineering Laboratory (INEL). The Idaho National Engineering Laboratory (INEL) proposes using depleted uranium concrete (known as "Ducrete") as a shielding material for spent nuclear fuel in future storage containers, such as the multi-purpose container (MPC) being developed by the Department of Energy (DOE) (INEL 1994). The depleted uranium inventory would be converted to uranium dioxide ($UO_2$) powder and fabricated into pellets. These $UO_2$ pellets would be substituted as aggregate in making Ducrete for use in shielding or as a form for disposal.

Standard concrete is a mixture of cement, sand ($SiO_2$), and aggregate (gravel, usually $SiO_2$ forms). However, by substituting a uranium oxide in the place of either the sand, the gravel, or the aggregate, a depleted uranium concrete, or Ducrete, can be produced, which has a higher density than standard concrete. This package will discuss production of and uses for Ducrete made from $UO_2$.

### 1.1 General Information

The depleted uranium must first be converted to $UO_2$.[1] The $UO_2$ conversion process produces a powder which is susceptible to further oxidation and is of low density compared to its theoretical density. Therefore, extra processing is required to "stabilize" and densify the conversion product prior to use as an aggregate for Ducrete (Murray 1994). This can be accomplished by sintering the $UO_2$ powder at 1000°C to form dense cylindrical pellets of approximately 5mm in diameter and 10mm in height, suitable for shielding applications.

### 1.2 Input Materials

The major input materials for the production of Ducrete from $UO_2$ include cement, uranium oxide "sand," and $UO_2$ aggregate in the form of pellets. The ratios of these materials are presented in Table 1 (Lessing et al.).

[1]See Information Packages 6, 7, 8, and 9 for a discussion of conversion processes.

*Table 1. Ratio of Materials for Ducrete*

| Material | Quantity |
|---|---|
| Cement | 1 part |
| Uranium oxide "sand" | 2 parts |
| $UO_2$ aggregate | 14 - 18 parts |

The uranium oxide "sand" can be either $UO_2$ or $U_3O_8$ powder. However, $UO_2$ powder will slowly oxidize in air at ambient temperature, which could cause defects in the Ducrete. For this reason, $U_3O_8$ powder is preferred for the "sand" element (Murray 1994).

## 1.3 Ducrete Applications

Ducrete could be used as shielding for storage/disposal containers for spent nuclear fuel (SNF) and as a hardened structure material for shelters or storage buildings. Additionally, Ducrete could be used as a disposal form at any of the low-level waste (LLW) disposal sites. These alternatives are further addressed below.

*Storage/Disposal Containers*

The commercial nuclear fuel container industry currently manufactures cylindrical containers of either concrete, steel, or iron for at-reactor storage of SNF (Quapp 1994). The concrete containers use approximately 70 cm of concrete as shielding and weigh approximately 118 MT fully loaded. Since Ducrete is denser than standard concrete, a Ducrete container would require less thickness (only about 30 cm) to ensure adequate attenuation of neutron and gamma radiation, resulting in a smaller and lighter container (about 90 MT fully loaded) (Quapp 1994, INEL 1994).

The following concepts are currently under consideration:

(1) Storage-only Vessel. Modeled after the commercial concrete container, this is an onsite concrete storage vessel with an inner metallic thin-walled canister for storing SNF prior to disposal (Haelsig 1994).

(2) Transportable Storage System. This design uses a Ducrete cask which could be loaded and sealed within the reactor fuel pool. This cask could then be either used for onsite storage or transported via a transportation overpack to a repository or into monitored retrievable storage, without opening the cask and risking worker exposure (Haelsig 1994). This is similar to the Multi-Purpose Cask concept currently being developed by DOE's Office of Civilian Radioactive Waste Management.

Given the projected removal schedule for commercial SNF through the year 2030, approximately 3,500 canisters may be required for storage and/or transport (Haelsig 1994).

*Hardened Structures*

Ducrete could be used to replace standard concrete in structures such as the NATO aircraft shelters or weapons storage bunkers. The higher density of the Ducrete produces greater resistance to impacts from weapons and debris. Currently, over 4,500 shelters exist within NATO and other allied countries (Cooley 1994). Any upgrades to these existing structures or construction of new facilities could be accomplished using Ducrete. However, current plans for upgrades or new construction are not known at this time.

*Disposal*

Disposal of depleted uranium in either the form $UO_2$ or $U_3O_8$ would generally require encapsulating it in a concrete or a polymer, resulting in large increases in disposal volume.[2] INEL proposes using the sintered $UO_2$ pellets as a uranium oxide "rock" for disposal, resulting in higher disposal densities and lower total disposal volumes (by about 60%) (INEL 1994). Additionally, if this form of uranium oxide "rock" does not meet the waste acceptance criteria of the disposal sites, it could be further encapsulated as Ducrete. This alternative would result in a lesser total disposal volume than encapsulation in standard concrete. (Murray 1994)

[2]See Information Package A1.

## *EVALUATION FACTORS*

## A. ENVIRONMENT, SAFETY, AND HEALTH

### A.1 Operations, Transportation, Handling, Storage, and Disposal

The primary environmental, safety, and health considerations associated with the fabrication of Ducrete result from the conversion of $UF_6$ to $UO_2$.[3] No unusual environmental, safety, or health concerns are anticipated in the production of $UO_2$ pellets or Ducrete. No additional dusting and contamination concerns exist that have not been addressed by existing $UO_2$ and LLW cement encapsulation plants (Murray 1994).

### A.2 Siting Factors

Several firms currently fabricating SNF storage containers could probably adapt their operations to produce Ducrete containers. Some of these facilities are licensed by the NRC (Haelsig 1994). If another facility were required, it would also have to be licensed.

### A.3 Public and Worker Safety

The radiological hazards associated with depleted uranium, regardless of form, are primarily due to alpha particle emission, meaning that the uranium would have to be ingested or inhaled to present a health hazard. Therefore, external radiation hazards associated with $UO_2$ handling are generally not a major concern. Historically, the chemical toxicity of uranium has been the primary concern for occupational exposure to depleted uranium, for which Occupational Health and Safety Administration (OSHA) standards exist (Hertzler 1994).

## B. WASTE MANAGEMENT

The wastes of primary concern for this alternative are generated as a result of the conversion from $UF_6$ to $UO_2$.[4] No hazardous or radioactive wastes are produced in fabricating either the aggregate from $UO_2$ or the Ducrete itself. However, once the Ducrete application is no longer required, Ducrete would have to be disposed of as a low-level radioactive waste. This leaves a degree of uncertainty as to future decommissioning and disposal cost liabilities (Haelsig 1994).

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[3]See Information Packages 6, 7, 8, and 9 for a discussion of the environmental, safety, and health issues associated with the conversion processes.

[4]See Information Packages 6, 7, 8, and 9 for a discussion of the wastes associated with the conversion processes.

## C. COST

Overall production costs of Ducrete are higher than production of standard concrete, primarily due to the conversion costs to obtain $UO_2$.[5] The estimated cost increases for using $UO_2$ Ducrete range from 20-50% over conventional concrete (Murray 1994).

Low-cost, high-throughput methods for producing dense forms have yet to be developed. Currently, EG&G estimates fabrication of the $UO_2$ aggregate, using conventional pellet-based techniques, to be approximately $1.00 per pound of $UO_2$ powder, and Ducrete fabrication to be approximately 5.5¢ per pound (Quapp 1994).

EG&G has also estimated that a Ducrete storage container could cost from $400,000 to $500,000, and a Ducrete storage container with overpack for transportation could total about $800,000 (Quapp 1994).

## D. TECHNICAL MATURITY

Ducrete production has been through preliminary testing (Lessing et al.), but remains largely undeveloped. DOE has funded process development efforts in FY 1995 to assess options for large-scale, low-cost fabrication methods (INEL 1994).

## E. SOCIOECONOMICS

### E.1 Employment

No employment data for producing Ducrete from $UO_2$ are available at this time.

### E.2 Public Acceptance

No evaluation of public acceptance has been made at this time.

### E.3 Local/Regional Development

No data on local and regional development for producing Ducrete from $UO_2$ are available at this time.

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[5] See Information Packages 6, 7, 8, and 9 for a discussion of the costs associated with the conversion processes.

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# INFORMATION PACKAGE
# C1

# Storage of $U_3O_8$

This Information Package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on Depleted $UF_6$ technologies or applications currently under consideration by the Department of Energy. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; it is intended to provide sufficient information to assist the Independent Technical Reviewer.

# *STORAGE OF $U_3O_8$*

## 1. OVERVIEW

This information package briefly describes an application for storage of depleted triuranium octaoxide ($U_3O_8$). It also provides supplemental data on environment, safety, and health; waste management; cost; technical maturity; and socioeconomics to assist in the evaluation of the Request for Recommendation submittal from Gencorp Aerojet Ordnance and Babcock & Wilcox.

Gencorp Aerojet proposes to reduce depleted uranium hexafluoride ($UF_6$) to depleted uranium tetrafluoride ($UF_4$) and then to metal for further processing into products and/or for storage. Mention is also made of the option of storage as $U_3O_8$. Gencorp Aerojet states that the main benefit of depleted $U_3O_8$ is that it is stable in air.

Due to the reactive nature of $UF_6$, the depleted uranium inventory may be converted to another form such as $U_3O_8$ prior to storage[1]. According to Martin Marietta, $U_3O_8$ is one of the most inert chemical forms of uranium, can be stored safely, and has the lowest potential impact on people and the environment. Major advantages of $U_3O_8$ are the relatively low chemical reactivity, solubility, and risks compared to alternate uranium forms. $U_3O_8$ is insoluble even in the weak acids and bases typically found in soils and groundwater (Martin Marietta, 1990).

### 1.1 Storage Regulations

Consistent with definitions established in the Atomic Energy Act (AEA), depleted uranium, in any chemical form, has been considered a source material by the Department of Energy (DOE). In regulations implementing the Resource Conservation and Recovery Act (RCRA), the Environmental Protection Agency (EPA) states that source materials, as defined by the AEA, are not solid wastes (40 CFR 261.4[a]). However, as a result of changes in federal statutes and regulations under the auspices of the Nuclear Regulatory Commission (NRC), the EPA, and the DOE, the regulatory requirements for storage and disposal of depleted uranium are being deliberated and may change (Hertzler 1994).

The depleted $UF_6$ exiting the separation cascades of the enrichment process are known as tails and could be a potential resource. The Claiborne Enrichment Center's (CEC) possession limit for the tails will be 80,000 metric tons (88,200 tons) of depleted $UF_6$ or the amount of depleted $UF_6$ produced during 15 years of CEC operations, whichever is less.

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[1]For more information on the conversion of $UF_6$ to $U_3O_8$, see Information Packages 1 and 2.

Thus, no later than 15 years after the commencement of CEC operations, the transportation of depleted $UF_6$ offsite for disposal will commence. Due to the reactivity of depleted $UF_6$ with water, the tails will be converted to a more chemically stable form before disposal/storage at an offsite facility. From the standpoint of potential long-term stability in the environment, the depleted $UF_6$ will most likely be converted to $U_3O_8$. The solid $U_3O_8$ generated in the conversion reactor will be separated from the effluent gas and will then be loaded into drums for transfer to a disposal/storage facility (NRC 1994).

## 1.2 Storage Options

Triuranium octaoxide is a product of mining uranium ores. It is converted into $UF_6$, enriched, converted into uranium dioxide ($UO_2$), and subsequently pressed into fuel pellets for use in the nuclear fuel industry. The $U_3O_8$ material, which is only stored temporarily, is stored and shipped in steel, plastic-lined, 55-gallon drums. The drums are usually stored inside a building.

Cogema, Inc., operates the only production-scale plant in the world for converting depleted $UF_6$ to $U_3O_8$. Located at the Tricastin site in the Rhone Valley in France, this plant, which began operation in 1984, converts depleted $UF_6$ into $U_3O_8$. Currently, Cogema packs and stores the $U_3O_8$ product in metal containers with a volume of 3 cubic meters each. Each container has a capacity of 9 tons. The containers, which are placed on concrete pads, are housed in metal framed, seismic resistant modular sheds. Each shed has a capacity of 2,600 containers. Twelve sheds are located onsite, providing storage capacity of 280,800 metric tons (MT) of $U_3O_8$. The current rate of $UF_6$ to $U_3O_8$ conversion is 16,000 MT/year. At the present rate of conversion, Cogema expects to be able to store 20 years' worth of production (Cogema 1989).

## *EVALUATION FACTORS*

## A. ENVIRONMENT, SAFETY, AND HEALTH

### A.1 Operations, Transportation, Handling, and Storage

The storage of $U_3O_8$ presents no unique environmental, safety, and health considerations. Under normal environmental conditions, $U_3O_8$ is insoluble even in the weak acids and bases typically found in soils and groundwater (Martin Marietta 1990). However, the potential exists for worker intake of uranium from accidental releases of $U_3O_8$. NRC regulations under 10 CFR Part 20 limit intake of soluble uranium because of its chemical toxicity (NRC 1994).

According to a study by Martin Marietta, $U_3O_8$ is one of the most inert chemical forms of uranium, with relatively low chemical reactivity, solubility, and risks compared to other forms of uranium.

### A.2 Siting Factors

Based on the Cogema experience, storage of $U_3O_8$ is likely to be retrievable, above ground, and inside in some structure (e.g., shed, vault) in order to comply with DOE double confinement regulations (e.g., stored in metal containers and housed inside a permanent structure) (DOE 1993).

### A.3 Public and Worker Safety

External radiation hazards associated with $U_3O_8$ handling are generally not a major concern. The radiological hazards associated with depleted uranium, regardless of form, are primarily due to alpha particle emission, meaning that the uranium would have to be ingested or inhaled to present a health hazard. Historically, the chemical toxicity of uranium has been the primary concern for occupational exposure to depleted uranium, for which Occupational Safety and Health Administration (OSHA) standards exist (Hertzler 1994).

## B. WASTE MANAGEMENT

No additional hazardous or radioactive wastes are produced as a result of $U_3O_8$ storage.

## C. COSTS

Storage

Costs for current storage of $U_3O_8$ at the Tricastin site were not available. In the United States, continued storage of the $UF_6$ cylinders at the three gaseous diffusion plants, through the year 2020, is estimated to range from $83 to $129 million, based on current practices. This estimate includes any necessary/planned new facility construction and increased maintenance and inspection activities (Hertzler 1994).

Transportation

The cost for shipping the $U_3O_8$ drums is 10 cents/drum (Davis Transport 1995).

## D. TECHNICAL MATURITY

Cogema has been storing $U_3O_8$ at its Tricastin site since 1984 (Cogema 1994). The $U_3O_8$ is stored in metal boxes with a volume of 3 cubic meters each, and housed inside monitored/retrievable storage (MRS) facilities. As described earlier, there are no technical development needs associated with $U_3O_8$ storage.

## E. SOCIOECONOMICS

Employment

Limited employment impact would result from operation of a $U_3O_8$ storage facility.

Public Acceptance

No formal evaluation of public acceptance has been made at this time.

Local/Regional Development

Local and regional development resulting from operation of a $U_3O_8$ storage facility cannot be measured at this time.

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# INFORMATION PACKAGE C2

# Storage of $UF_6$

This information package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on depleted $UF_6$ technologies or applications currently under consideration by the Department. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; they are intended to provide sufficient information to assist the Independent Technical Reviewer.

# *STORAGE OF DEPLETED URANIUM HEXAFLUORIDE*

## 1. OVERVIEW

This information package briefly describes an application for the storage of depleted uranium hexafluoride ($UF_6$). It also provides supplemental data on environment, safety, and health; waste management; cost; technical maturity; and socioeconomics, to assist in the evaluation of the following Request for Recommendation (RFR) submittals:

- A. N. Tschaeche (RFR No. 1);
- Frank Shall, Cogema, Inc. (RFR No. 6);
- Alan E. Waltar, American Nuclear Society (RFR No. 10)
- Corinne Whitehead, Coalition for Health Concern (RFR No. 16)
- Ronald Lamb (RFR No. 20);

The U.S. Department of Energy (DOE) currently manages an inventory of depleted $UF_6$ in long-term storage at these active and deactivated gaseous diffusion plants (GDPs) in Kentucky, Ohio, and Tennessee. The current inventory totals approximately 560,000 metric tons in 47,000 cylinders, and is distributed across the three sites as follows:

| | |
|---|---|
| - Paducah, KY, Gaseous Diffusion Plant (PGDP) | 29,000 (62%) |
| - Portsmouth, OH, Gaseous Diffusion Plant (PORTS) | 13,000 (28%) |
| - Oak Ridge, TN, K-25 Plant | 5,000 (10%) |

Depleted uranium has been stored at the three gaseous diffusion plants in 10- and 14-ton steel cylinders as pure (99.9%) $UF_6$. Typically, the cylinders are stored outdoors on concrete-paved or compacted gravel surfaces. They are stacked in double rows using a two-tier configuration (the lower tier of cylinders is placed on wooden or concrete saddles for support above the ground surface). Some of the cylinders have been stored in this manner for over 30 years (Hertzler 1994). Other storage options may exist, such as vault storage or monitored retrievable storage.

In the meantime, present DOE management strategy is to continue storing the depleted uranium as $UF_6$ until future uses are developed. If appropriate and feasible uses are not found by approximately 2010, then steps would be taken to convert the depleted $UF_6$ to triuranium octaxide ($U_3O_8$) as the most appropriate form for ultimate storage and disposition.

DOE has prepared several program plans to establish surveillance and maintenance requirements for the continued safe storage of the three-site inventory (Hertzler 1994). The oldest cylinders have an estimated useful life expectancy of 30 years. The current cylinder management program consists of inspection to verify cylinder integrity, technical assessments to improve inspection

techniques and determine corrosion rates/impacts, and cylinder stabilization projects to improve storage conditions and the effectiveness of inspections.

Ongoing DOE activities to identify and minimize corrosion of the depleted $UF_6$ cylinders are as follows:

Surveillance and Maintenance

- Baseline cylinder conditions: visual inspections to verify present condition and fitness for continued safe storage. By using coded anomalies, a database is maintained for tracking and trending inspection data.

- Periodic risk-based inspections to monitor cylinder conditions: High-risk cylinders (i.e., poor drainage, heavy scale or pitting, suspect leaking valves or plugs) are inspected annually (approximately 15,000 cylinders ). One-fourth of the remaining inventory is inspected each year.

- Valve maintenance and replacement: Missed or cracked parts identified during the periodic inspections are replaced, as well as any necessary valves.

- Other maintenance: Activities include removal of debris from cylinder skirts, clearing plugged drain holes, and yard maintenance.

Technical Assessments

- Cylinder corrosion monitoring activities: Several studies are underway (e.g., coupon corrosion rates, time-of-wetness studies) to determine factors which impact corrosion and corrosion rates.

- Valve leak status monitoring: determination of leak status, including health physics surveys, valve decontamination, hydrogen fluoride (HF) monitoring, and acoustic emissions.

- Cylinder thickness characterizations: A system to baseline shell thickness is being developed. Ultrasonic testing of corroded cylinders will be used to determine wall thickness and approximate rate of thinning.

- Coating and cleaning technology evaluations: determining optimum protective coatings and methods of removing debris which may contribute to corrosion.

Cylinder Stabilization

- Cylinder yard improvement projects include replacing wood "saddles" (storage chocks) with concrete, and refurbishing existing yards.

- New cylinder yard construction projects: Several new storage yards are planned or under construction at Paducah and Portsmouth.

- Movement of cylinders in poor storage conditions involves restacking cylinders to allow full inspection and moving cylinders out of poor drainage areas.

- Refurbishment/replacement of damaged or heavily corroded cylinders: application of protective coatings to high-risk cylinders or emptying cylinders too damaged/corroded to continue in storage.

    - Construction of a cylinder refurbishment facility is scheduled for completion in 1998. This facility will have the capacity to refurbish approximately 2,200 cylinders per year.

(Sources: MMES 1994, ORNL 1995.)

## 1.1 Storage Regulations

The Atomic Energy Act (AEA) of 1954 designated depleted uranium as a "source material." Therefore, it is not subject to the requirements of the Resource Conservation and Recovery Act (RCRA).

Regarding storage, DOE regulations state that all radioactive materials, including depleted uranium, must be contained by two levels of confinement (e.g., contained in a cylinder and housed in a building) (DOE 1988, DOE 1993). DOE has not implemented this requirement for depleted $UF_6$ cylinders, as the current storage methods were in practice long before it was established.

In the commercial environment, the U.S. Nuclear Regulatory Commission (NRC) recently reviewed storage of depleted $UF_6$ in conjunction with the development of the Environmental Impact Statement (EIS) for the Claiborne Enrichment Center (CEC) for Louisiana Enrichment Services. The EIS limited the amount of depleted uranium to be stored onsite to 80,000 metric tons or the amount of tails material accumulated over 15 years of operation, whichever came first (NRC 1994). This arrangement is similar to that of Cogema, Inc., in France, where safety authorities have established a maximum storage limit for $UF_6$ of 50,000 tons uranium (equivalent to approximately 75,000 tons of $UF_6$) onsite in the operating license for the Cogema facilities (Shallo 1994).

## *EVALUATION FACTORS*

## A. ENVIRONMENT, SAFETY, AND HEALTH

When $UF_6$ is released into the atmosphere, it reacts with the moisture in the atmosphere to form uranyl fluoride ($UO_2F_2$) and HF. Hydrogen fluoride is a corrosive and irritating acid vapor that can severely harm the lungs and skin if exposed to sufficient concentrations. The $UO_2F_2$ forms a particulate, which is very soluble in the lungs, and can be carried away by the wind and deposited onto the ground. As the released material is dispersed, an individual offsite could be exposed to the plume carrying these chemicals. Where it is highly concentrated, the plume is visible and could be immediately irritating to the lungs. The immediate effects from the exposure to these chemicals are edema of the lungs, skin irritation from exposure to HF, and renal distress due to heavy metal (uranium) intake. The fluorides ($UO_2F_2$ and HF) can cause poisoning if intakes are large. The radiation effect is very minor, since depleted uranium is a mildly radioactive material.

The HF could also have an immediate effect on nearby vegetation, cattle, and other animals. When the $UO_2F_2$ and HF are deposited on the ground, there may be some residual effect on the environment (NRC 1986).

### A.1 Operations, Transportation, Handling, and Storage

Special consideration must be given to the way $UF_6$ is transported, handled, and stored.

#### Transport

In general, the transportation of radioactive materials is regulated under 10 CFR Part 71 (*Packaging and Transport of Radioactive Material*) and 49 CFR (*Transportation*). The transport of low-specific-activity radioactive materials, such as depleted $UF_6$, is governed by Department of Transportation regulations, contained in 49 CFR (Hertzler 1994). $UF_6$ cylinders are frequently transported to and from the GDPs in accordance with existing procedures (DOE1991). No new environmental, safety, and health considerations are anticipated in the transport of depleted $UF_6$ cylinders.

#### Operations, Storage and Handling

According to an analysis by Martin Marietta Energy Systems (MMES), many of the cylinders now in storage are not properly arrayed to permit the levels of monitoring necessary to assure continued containment integrity, and these cylinders need to be restacked. Cylinder handling activities pose a small but significant hazard. For example, contacts made during stacking or unstacking of the cylinders can, under a limited set of circumstances, generate small cracks that extend through the cylinder walls, thus setting the stage for leakage of the contents. If these

cracks are not detected at inception, they can grow through corrosion of the steel by the HF that is generated by reaction of moist air with the cylinder contents. Handling accidents can also result in the bending (and consequent leakage) or breaking of valves. Neither situation causes leaks of catastrophic dimensions, since the cylinder contents are under negative pressure. Both types of leaks tend to be self-sealing, but they release small amounts of uranium compounds and HF from the cylinder (MMES 1992).

For more than 40 years, handling of $UF_6$ in the enrichment plants has been remarkably free of incidents with the potential for damage to the environment or to plant or community health or safety. Cylinder improvements have been made over the decades of $UF_6$ storage. The risk of releases of $UF_6$ to the environment because of valve failure was recognized as a potential problem early in the enrichment program. The industry-standard fluorine valve used for $UF_6$ cylinders was redesigned, and the new valve has been subject to only minor problems since its introduction in the mid-1950s. Hazards associated with potential cylinder rupture because of handling accidents were reduced by administrative procedures prohibiting intraplant transport of liquid-filled cylinders (dating from about 1978), and the potential for brittle fracture during cylinder handling operations in winter gave rise to the specification of a steel with certified low-temperature impact response in all cylinder procurements since 1979. The observation of lamellar tearing resulting from low-level impact during handling operations in shipping/storage led to a further modification of the specification for cylinder steels in 1984. Greater resistance to damage from handling contacts is now assured through the use of steels with a low sulfur content, which improves ductility and impact strength in the short transverse (through-thickness) direction (MMES 1992).

## A.2 Siting Factors

Depleted $UF_6$ is currently stored onsite at the three GDPs. The DOE has no plans for relocating the inventory to continue storage. If $UF_6$ storage were transferred to non-DOE facilities, they would have to obtain an NRC license in accordance with 10 CFR Part 40 (*Application for Specific Licenses*).

## A.3 Public and Worker Safety

The radiological hazards associated with depleted uranium, regardless of form, are primarily due to alpha particle emission, meaning that the uranium would have to be ingested or inhaled to present a health hazard. Historically, the chemical toxicity of uranium has been the primary concern for occupational exposure to depleted uranium, for which Occupational Safety and Health Administration (OSHA) standards exist (Hertzler 1994).

In the event of an accidental spill of $UF_6$ during handling, personnel in the immediate area are at risk of exposure to high concentrations of HF. HF is a corrosive and irritating acid vapor that can severely harm the lungs and skin if exposed to sufficient concentrations. The immediate effects

from exposure to these chemicals are edema of the lungs, skin irritation from exposure to HF, and renal distress due to heavy metal (uranium) intake. The fluorides ($UO_2F_2$ and HF) can cause poisoning if intakes are large.

## B. WASTE MANAGEMENT

### B.1 Waste Storage, Transportation, Treatment or Disposal

There do not appear to be any unique waste management concerns with the storage of depleted $UF_6$. No wastes are expected to be generated from storage activities.

### B.2 Recycling Potential

No recycling potential from depleted $UF_6$ storage is expected.

## C. COSTS

Costs are based upon 1992 estimates developed for the K-25 storage cylinders, and have been extrapolated to cover all sites. Total cost to maintain current storage practices through FY 2020 is estimated to be approximately $92M (FY 1992 dollars). This includes completing ongoing upgrades of cylinders and yards, new automated cleaning/coating facilities at each site, new storage yards for the refurbished cylinders at K-25, Portsmouth, and Paducah, and the continuation of current inspection and maintenance programs (Hertzler 1994). Capital equipment costs of $630,000 are assumed for each GDP to cover purchases of cylinder stackers and straddle carriers. A total of 15,000 new saddles will be required for cylinders on the three sites.

Based on the above estimate, life cycle cost estimates (in 1992 dollars) ranging from $83 million to $129 million were determined for storing the depleted $UF_6$ through the year 2020. This corresponds to storage costs of $0.22/kgU to $0.34/kgU, assuming a storage inventory of 375,000 MTU (Hertzler 1994).

At this time no estimates have been developed of the cost to meet the double confinement requirements of the DOE Orders. However, indoor storage capital costs were estimated at $360 million to accommodate the total three-site inventory (MMES 1990).

## D. TECHNICAL MATURITY

The DOE has been storing depleted $UF_6$ at the GDPs since the mid-1940's, when the first plant to use the gaseous diffusion process for uranium enrichment began operation in Oak Ridge, Tennessee. It is recognized that improved storage methods are necessary, and preliminary steps have been taken to address the situation (Hertzler 1994).

## E. SOCIOECONOMICS

Employment

Limited employment impact would result from continued storage at the GDPs. Potential impacts from the construction and operation of new storage facilities cannot be measured at this time.

Public Acceptance

Several responses to the Advance Notice of Intent express concern about current storage practices for depleted $UF_6$. These responses indicate that the general public will not accept continued storage of depleted uranium at the GDPs without improvements.

Local/Regional Development

Local and regional development resulting from the construction and operation of a depleted uranium storage facility cannot be measured at this time.

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3Request for Recommendation #1.

4Request for Recommendation #10.

5Request for Recommendation #16.

# INFORMATION PACKAGE
# D1/E1

# Potential Use of Depleted Uranium as Fuel in Thermal and Breeder Reactors

This information package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on depleted $UF_6$ technologies or applications currently under consideration by the Department. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; they are intended to provide sufficient information to assist the Independent Technical Reviewer.

# *POTENTIAL USE OF DEPLETED URANIUM AS FUEL IN THERMAL AND BREEDER REACTORS*

## 1. OVERVIEW

This information package briefly describes the use of depleted uranium (DU) as a nuclear reactor fuel, both in sodium-cooled Fast Breeder Reactors (with external spent fuel reprocessing and recycle) and in Light Water Reactors (LWRs) in the form of $UO_2$ within mixed oxides (MOX), and as a fuel in Integral Fast Reactors (IFRs) in the form of DU metal. This information package also provides supplemental data on environment, safety, and health; waste management; cost; technical maturity; and socioeconomics, to assist in the evaluation of Request for Recommendation (RFR) submittals from

- A.N. Tschaeche (RFR No. 1);
- Patrick F. Brown (RFR No. 9);
- Alan E. Waltar, American Nuclear Society (RFR No. 10);
- N. Dean Eckhoff, Head, Department of Nuclear Engineering, Kansas State University (RFR No. 17).

This information package relates to the possible utilization of depleted uranium as a fuel for current generation reactors, as well as for those in the demonstration and developmental stages. In order to evaluate DU's potential for reactor fuel applications, it is important to understand the rationale behind the production and stockpiling of DU itself. When the gaseous diffusion plants were constructed for the production of highly enriched uranium for weapons, it was recognized that they would also eventually produce slightly enriched uranium to fuel the first generation of civilian light water-moderated power reactors. At the same time, the depleted $UF_6$ remaining from the enrichment process was considered to be a valuable energy resource for a future generation of sodium-cooled Fast Breeder Reactors (FBRs).

FBRs operate in the fast neutron spectrum where DU would be fissionable. It was assumed that Fast Breeder Reactors would be economical when natural uranium became scarcer and more expensive, at which time the ability of FBRs to consume U-238 would support their replacing LWRs, which largely consume U-235 (the uranium isotope with only 1/140th the concentration of U-238 in natural uranium). Although slowed growth of nuclear power beginning around 1975 (the first year in which there were zero net orders for nuclear plants) meant that there would be a plentiful supply of natural uranium, several demonstration FBRs were built in Europe, and the French built two large FBRs (Phenix and Super-Phenix).

This overview would not be complete without recognition of a number of both economic and practical factors, which would have strong bearing on the future use of DU as a reactor fuel. Two of these deserve special emphasis:

(1) All fast breeders, and most LWRs outside the U.S., utilize reprocessing and recycle of spent fuels. This restricts the amount of new fuel required to make up for recycle losses and reactor burn-up. Make-up requirements are rather small compared to initial core loadings. Even if it were to supply make-up, DU would have to compete with natural uranium, as noted in factor (2) below.

(2) Fuel for the once-through (throw-away) fuel cycle utilized by U.S. LWRs has always been derived from the same source: natural uranium enriched to 3-5% U-235. However, an alternate source of fuel for these reactors will soon emerge. The U.S. Enrichment Corporation has contracted with the Russian government, which will supply 4% U-235 in $UF_6$, derived by blending highly enriched uranium or HEU (>90% U-235) with natural uranium. It should be noted that in both cases (enrichment and blending), it has been found cheaper to blend high fissile assay Pu or HEU with natural uranium, which contains 0.7% U-235, rather than with DU, which only contains 0.2% U-235.

Thus, with the exception of the use of DU in the blankets of sodium-cooled FBRs, for which it has no competitor, other reactor fuel uses for DU must be considered within the context of these two factors.

## 1.1 Mixed Oxide Fuels: Process Description

### 1.1.1 Use of DU in Light Water Reactor Fuels as Mixed Oxide

One reuse option that has been considered for DU is the conversion of depleted $UF_6$ to $UO_2$ for blending with plutonium dioxide ($PuO_2$) or highly enriched $UO_2$ for the production of mixed oxide fuels (MOX) for LWRs. Currently, mixed oxide fuels are used in Europe, where reprocessing of spent LWR fuels yields considerable plutonium and slightly enriched uranium which can be recycled. Japan is also pursuing plutonium recycle and MOX fuels. The once-through mode of LWR fueling utilized in the U.S., in the absence of reprocessing, would mean that MOX fuels would require either highly enriched uranium or plutonium from weapons stockpiles as the fissile component. Thus, for the uranium component, DU would be competing with natural uranium as a blend to bring the fissile concentration in LWR fuels down to 4-5%.

The LWR fuel cycle using recycled uranium and plutonium in MOX fuel is shown in Figure 1. This recycling process is currently implemented in Europe, with an annual capacity of approximately 200 MTHM (metric tonnes of heavy metal), increasing to about 300 MTHM within the next three years. The once-through (throw-away spent fuel) cycle used in the U.S. is shown in Figure 2. Although this figure shows fresh reactor fuel to be supplied from enrichment plants, there is the option (not currently chosen) of blending weapons uranium or plutonium with DU or natural uranium for this purpose. As mentioned previously, all enriched uranium is currently supplied from enrichment plants. If MOX fuels were used, DU would be in competition with natural uranium.

#### 1.1.1.1 Input Materials

As may be noted from Figure 1, the materials used (in Western Europe) to fabricate MOX reactor fuels for Light Water Reactors are (1) slightly enriched $UF_6$ recovered from spent fuel recycling (re-enriched to about 3% U-235, then converted to $UO_2$), (2) plutonium recovered from spent fuel reprocessing (and converted to $PuO_2$). The only role shown for DU in Figure 1 is as feed to the Fast Breeder Reactor cycle, which will be considered here separately. If DU were to be used within the LWR cycle in the U.S., as in the Figure 2 spent fuel throw-away mode, it would have to be as a $UO_2$ blend with weapons uranium or plutonium, in place of enriched uranium from the enrichment plant. The quantities involved would be the following (Nuclear Energy Agency 1982):

| | |
|---|---|
| Initial Loading: | 78 tonnes U/GWe (metric tons U/GigaWatt-electric) |
| Equilibrium Cycle Charge: | 22 tonnes U/GWe-yr |

If DU was used, the annual consumption for a 100-reactor economy (i.e., the current level of nuclear power in the U.S.) would be 2,200 tonnes/year (about 1% of the current $DUF_6$ inventory).

#### 1.1.1.2 Products

The products of MOX fuel fabrication are fuel elements composed of arrays of fuel pins containing the MOX pellets. In addition, some scrap is generated from the cutting and machining of cladding, structurals, and fuel materials. The quantities of products will be approximately the same as stated above for input materials.

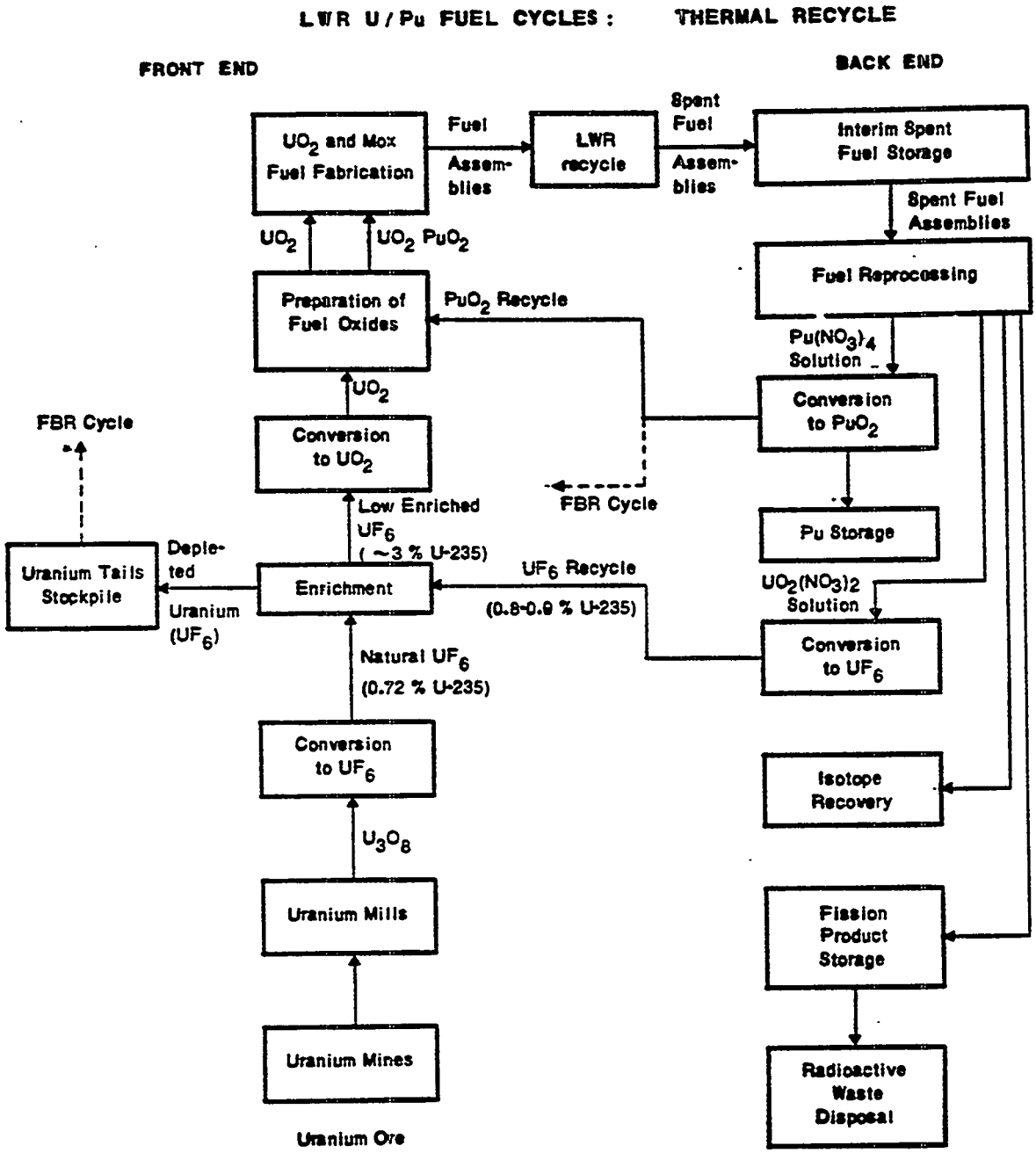

LWR U / Pu FUEL CYCLES : THERMAL RECYCLE
FRONT END
BACK END
UO2 and Mox Fuel Fabrication
Fuel Assem-blies
LWR recycle
Spent Fuel Assem-blies
Interim Spent Fuel Storage
Spent Fuel Assemblies
Fuel Reprocessing
UO2
UO2 PuO2
Preparation of Fuel Oxides
PuO2 Recycle
Pu(NO3)4 Solution
Conversion to PuO2
UO2
Conversion to UO2
FBR Cycle
FBR Cycle
Pu Storage
Low Enriched UF6 ( ~3 % U-235)
Depleted Uranium (UF6)
Uranium Tails Stockpile
Enrichment
UF6 Recycle
(0.8-0.9 % U-235)
UO2(NO3)2 Solution
Conversion to UF6
Natural UF6 (0.72 % U-235)
Conversion to UF6
Isotope Recovery
U3O8
Uranium Mills
Fission Product Storage
Uranium Mines
Radioactive Waste Disposal
Uranium Ore

**FIGURE 1**

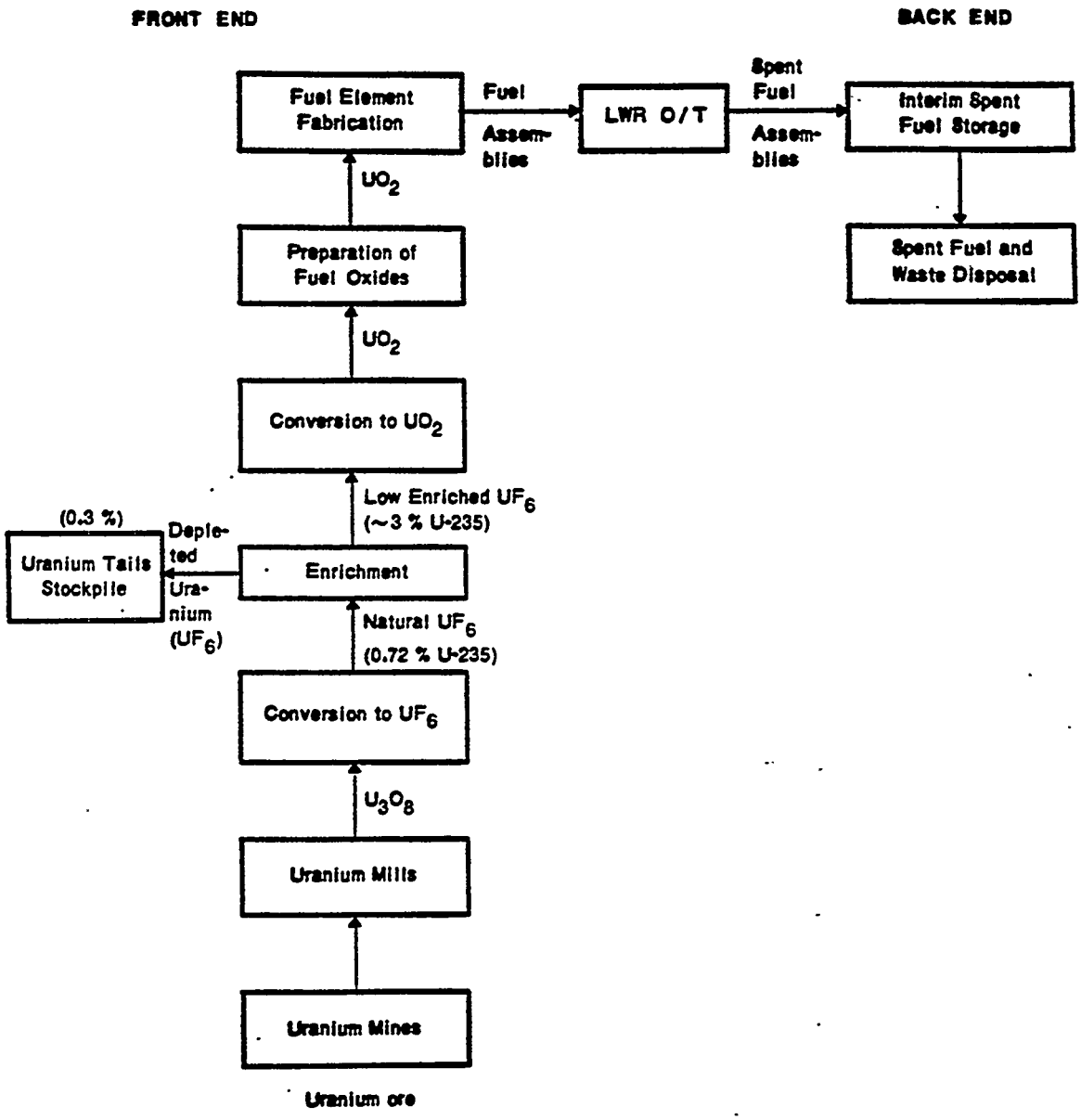

LWR U / Pu FUEL CYCLES : ONCE-THROUGH
(Throw-Away) Mode of Operation
FRONT END
BACK END
Fuel Element Fabrication
Fuel Assem-blies
LWR O/T
Spent Fuel Assem-blies
Interim Spent Fuel Storage
Spent Fuel and Waste Disposal
UO2
Preparation of Fuel Oxides
UO2
Conversion to UO2
Low Enriched UF6 (~3 % U-235)
(0.3 %)
Uranium Tails Stockpile
Deple-ted Ura-nium (UF6)
Enrichment
Natural UF6 (0.72 % U-235)
Conversion to UF6
U3O8
Uranium Mills
Uranium Mines
Uranium ore

**FIGURE 2**

### 1.1.2 Use of Mixed Oxide Fuels in Fast Breeder Reactors

The rationale for the use of DU in sodium-cooled Fast Breeder Reactors was outlined in the overview. The FBR reactor fuel cycle is illustrated in Figure 3. In Figure 3, the DU stockpile is utilized for uranium make-up, having been converted from $UF_6$ to $UO_2$ for MOX manufacture. Unlike the LWR cycle, the breeder cycle includes two discrete fuel types: a driver fuel, consisting of 20-30% plutonium in DU, and a blanket fuel, consisting of DU only.

#### 1.1.2.1 Input Materials

As shown in Figure 3, the input materials are DU as it now occurs in enrichment plant $UF_6$ tailings, recycled uranium from reprocessing (which is a necessary condition for the FBR), and recycled plutonium from reprocessing. All three streams are converted to oxides for MOX fabrication. The following quantities are involved (Nuclear Energy Agency 1982):

| | |
|---|---|
| Initial Loading: | 87 tonnes DU/GWe<br>3.14 tonnes Pu/GWe |
| Equilibrium Cycle Charge: | 40.3 tonnes DU/GWe-yr<br>2.10 tonnes Pu/GWe-yr |
| Equilibrium Cycle Discharge: | 38.8 tonnes DU/GWe-yr<br>3.46 tonnes Pu/GWe-yr |

In the equilibrium condition, DU consumption would be the difference between the equilibrium charge and discharge, or (40.3-38.80), or 1.5 tonnes of DU/GWe-yr. This relatively small consumption, compared with initial coreloadings, emphasizes the large amount of energy obtainable from even small DU burn-up and the efficiency of the approach.

#### 1.1.2.2 Output Materials

The outputs will be the fuel elements themselves, in addition to scrap. Since recycled fuels require glove-box fabrication, care must be taken both during the fabrication process and in the recovery of scrap materials to protect worker health and safety.

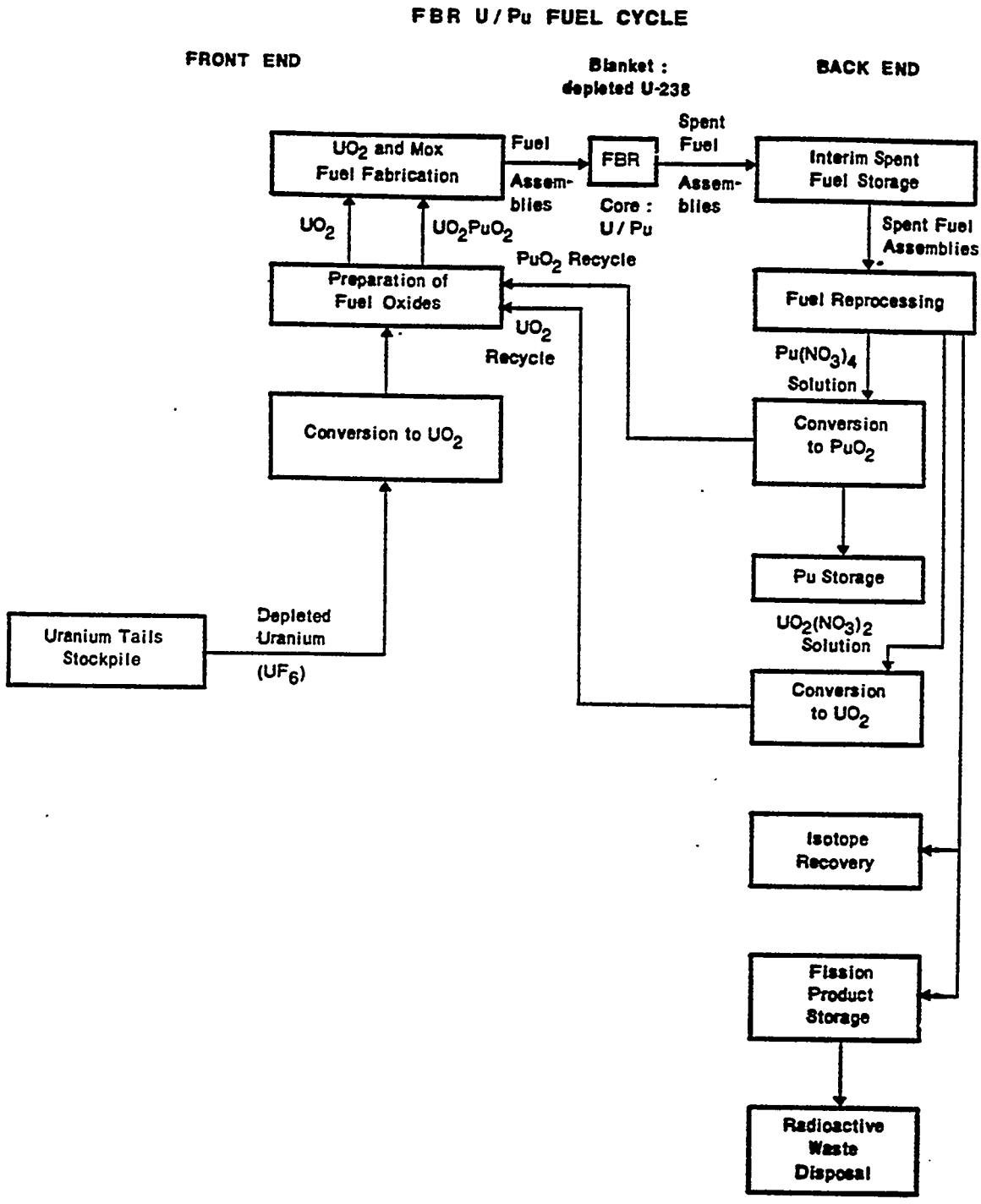

FBR U/Pu FUEL CYCLE
FRONT END
Blanket : depleted U-238
BACK END
UO2 and Mox Fuel Fabrication
Fuel Assem-blies
FBR
Core : U/Pu
Spent Fuel Assem-blies
Interim Spent Fuel Storage
Spent Fuel Assemblies
UO2
UO2PuO2
PuO2 Recycle
Preparation of Fuel Oxides
Fuel Reprocessing
UO2 Recycle
Pu(NO3)4 Solution
Conversion to UO2
Conversion to PuO2
Pu Storage
Uranium Tails Stockpile
Depleted Uranium (UF6)
UO2(NO3)2 Solution
Conversion to UO2
Isotope Recovery
Fission Product Storage
Radioactive Waste Disposal

**FIGURE 3**

## 1.2 Use of DU Metal as Fuel in Integral Fast Reactors (IFRs)

### 1.2.1 Process Description

A possible reuse option for depleted uranium metal is as the "make-up" uranium fuel for the Integral Fast Reactor, or IFR, an advanced pool-type reactor concept which utilizes metallic fuel and liquid sodium cooling. The terms "integral" and "make-up" must be emphasized, because the reactor concept is based upon an integrated fuel cycle with pyrometallurgical processing. The electrorefining step of this process allows valuable fuel constituents-uranium and plutonium-to be recovered and fission products to be removed. A notable feature of this step is that all other actinide elements (including uranium) accompany plutonium through the process. Burn-up and other losses are small, requiring relatively little uranium make-up. Thus, depleted uranium metal would again be in competition with uranium metal derived from natural uranium ($U_3O_8$) as make-up for burn-up and other losses, which, as noted above, are relatively small.

### 1.2.2 Input Materials

The history of the IFR concept, from its beginnings in the Argonne Experimental Breeder Reactor (EBR) Program through its integration with pyroprocessing, are detailed in a 1989 paper (Chang 1989). More recent experimental development was reported by Till and Chang in a November 1992 issue of Nuclear Engineering International (Till et al. 1992).

Throughputs of a pyroprocessing plant designed to support eight 1,395-MWe IFRs have been developed (Goodman 1995). Such a plant would reprocess 194.4 metric tons of heavy metal (MTHM) per year, and fabricate 217.2 MTHM per year, both as driver fuel and blanket fuel assemblies. The difference between these two figures (217.2 -194.4 = 22.8 MTHM/year) could be said to be due to burn-up and other losses, largely of uranium. For a 100-reactor economy (approximately 100 GWe), approximately 204 tonnes of DU could be used as the uranium source.

## EVALUATION FACTORS

## A. ENVIRONMENT, SAFETY AND HEALTH

In addition to the issues discussed below, there are also environmental, safety, and health issues associated with the conversion of $UF_6$ to $UO_2$[1] or DU metal[2].

### A.1 Operations, Transportation, Handling, Storage, and Disposal

The NRC and DOE classify depleted uranium as a low-level waste due to the radioactive nature of this material, regardless of its chemical form. Thus, wastes from manufacturing the fuels would be handled as LLW.

### A.2 Siting Factors

New facilities for the production of fuel for breeder reactors would have to obtain an NRC license in accordance with 10 CFR Part 40, *Domestic Licensing of Source Material.*

### A.3 Public and Worker Safety

The radiological hazards associated with depleted uranium, regardless of form, are primarily due to alpha particle emission, meaning that the uranium would have to be ingested or inhaled to present a health hazard. External radiation hazards associated with DU are generally not a concern. However, many of the potential uses of depleted uranium as nuclear reactor fuel also involve mixed oxides of recycled plutonium. The latter poses both a radiation hazard and an ingestion hazard, and many of the fuel fabrication procedures described in this package require glove-box/closed ventilation systems. Historically, the chemical toxicity of uranium has been the primary concern for occupational exposure to depleted uranium, for which Occupational Safety and Health Administration (OSHA) standards exist (Hertzler 1994).

(1) See Information Packages 6, 7, 8, and 9 for a discussion of the issues associated with the conversion to $UO_2$.
(2) See Information Packages 3, 4, and 5 for a discussion of the issues associated with the conversion to DU.

## B. WASTE MANAGEMENT

### B.1 Waste Storage, Transportation, Treatment, or Disposal

The wastes which would originate from the fuel fabrication involving DU and plutonium would be primarily low-level waste (LLW). Some transuranic waste (TRU) might also be generated. High-level waste (HLW) from reprocessing would be vitrified and sent to the planned repository.

## C. COSTS

MOX recycle to existing LWRs costs approximately the same as for the cnce-through cycle, based on the Eurpoean experience using recycled or natural uranium. Substitution of DU for natural or recycled uranium is expected to involve some extra costs. Costs for breeder reactors and their fuel cycles are not well developed at this time.

## D. TECHNICAL MATURITY

MOX fuel recycle to Light Water Reactors is currently implemented in Europe at a scale of several hundred tonnes per year. New plants are coming on line. These applications use natural and recycled uranium. At the present time, MOX fuel recycle is not practiced in the U.S., and the GEISMO *(Generic Environmental Impact Statement on Mixed Oxide Fuel Use)* has been allowed to expire.

Several prototype breeder reactors and fuel cycle facilities have been constructed and are in operation in Europe and Japan.

The IFR concept has been developed using existing DOE facilities (Experimental Breeder Reactor-2 and Hot Fuel Examination Facility). Key areas of the concept have been tested and demonstrated.

## E. SOCIOECONOMICS

### E.1 Employment

No employment data for production or use of breeder reactor fuels from $UO_2$ or DU metal is available at this time.

## E.2 Public Acceptance

No evaluation of public acceptance has been made at this time.

## E.3 Local/Regional Development

No data on local and regional development for production or use of breeder fuels from $UO_2$ or DU metal is available at this time.

## REFERENCES

A.E. Waltar. 1994. Letter to DOE. Recommendation for Potential Use of Depleted $UF_6$. American Nuclear Society.[3]

N. Dean Eckhoff. 1995. Letter to LLNL. Kansas State University.[4]

A.N. Tschaeche. 1994. Letter to DOE.[5]

P.F. Brown. 1994. Letter to LLNL. Proposed Disposition of Gaseous Diffusion Plants Depleted Uranium Hexafluoride.[6]

Nuclear Energy Agency. 1982. "Nuclear Energy and its Fuel Cycle" Organization for Economic Co-operation and Development, Paris.

Y.I. Chang. 1989. "The Integral Fast Reactor," Nuclear Technology 88.

C.E. Till and Y.I. Chang. 1992. "Integrating the fuel cycle at IFR," Nuclear Engineering International.

E. Goodman. 1995. Personal communication. Office of Nuclear Energy, U.S. Department of Energy.

[3] Request for Recommendation #10.
[4] Request for Recommendation #17.
[5] Request for Recommendation #1.
[6] Request for Recommendation #9.

# INFORMATION PACKAGE
# F 1

# HTGR Fuel Fabrication Using Uranium Carbide

This information package was prepared to describe potential uses or technologies that could facilitate the long-term management of depleted $UF_6$. The application described in this package was not included among the responses to the Department of Energy's Request for Recommendations. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; they are intended to provide sufficient information to assist the Independent Technical Reviewer.

# *HTGR FUEL FABRICATION USING URANIUM CARBIDE*

## 1. OVERVIEW

This information package describes an application for the fabrication of high-temperature gas-cooled reactor (HTGR) fuel using uranium carbide. It also provides supplemental data on environment, safety, and health; waste management; cost; technical maturity; and socioeconomics, to assist in the evaluation of this application for depleted uranium hexafluoride ($UF_6$).

Fuel fabrication plants for HTGRs convert uranium dioxide ($UO_2$), at various enrichments depending on the desired fuel cycle, and thorium dioxide ($ThO_2$) into fuel elements. Commercially, the favored HTGR fuel cycle is high enriched (93%) uranium (HEU) and thorium (Th). Potential HTGR fuel cycles using depleted uranium include a low enriched uranium (LEU) cycle, which would use a mixture of 5-15% enriched $UO_2$ and depleted $UO_2$, and a HEU cycle, which could be blended down with depleted uranium or recycled $^{233}U$ (from a previous HEU-Th cycle). This information package focuses on the commercial HEU-Th fuel cycle because its fabrication processes are more fully understood; information on the potential depleted uranium cycles is provided whenever possible. The amount of depleted $UF_6$ consumed by HTGR fuel fabrication depends greatly on the chosen fuel cycle. All fuel cycles would require the conversion of depleted $UF_6$ to $UO_2$ prior to fuel fabrication (see Information Packages 6/7/8 and 9). Although there are no commercial HTGRs currently operating in the United States, several have been operated in the past and advanced HTGR design work is underway.

### 1.1 HTGR Fuel Description

The most common HTGR approach is to use HEU as the fissile "driver" fuel and thorium as the fertile fuel. In this case, depleted uranium would need to be heavily re-enriched for HTGR fuel fabrication. This approach is designed to work with reprocessing to recover the fissile $^{233}U$ that is bred from Th during the fuel cycle as well as the remaining fissile $^{235}U$. A similar approach would use LEU as the driver fuel with depleted uranium as the fertile fuel. The advantage to this approach is that it would require little or no re-enrichment of depleted uranium and would consume a larger portion of the depleted $UF_6$. However, the neutronic properties of $^{238}U$ are expected to make the LEU cycle less favorable for "breeding" of fissile material than with thorium in the HEU-Th cycle.

#### 1.1.1 Fuel Element

As stated earlier, fuel fabrication plants for HTGRs convert enriched $UO_2$ and $ThO_2$ into HTGR fuel elements. The fuel element which is the basis of the HTGR concept consists of a hexagonal block of graphite into which vertical coolant and fuel holes are drilled. The fuel holes are filled

with rods consisting of a graphite sleeve containing a column of cylindrical fuel compacts. The individual elements are regular prisms approximately 79 cm high with a hexagonal cross section measuring approximately 36 cm across the flats. Coolant channels extend through each element and align with coolant channels in the elements above and below[1]. The fuel rod channels and coolant channels are parallel to each other and are distributed on a triangular array with two fuel channels for each coolant channel. Figure 1 shows the standard HTGR fuel element. In addition to fuel channels and coolant channels, fuel elements contain a small amount of boron carbide (BC), formed into rods, to act as burnable poison. Several elements also contain channels for control rods and instrumentation. Fuel elements for other HTGR fuel cycles are likely to be very similar to HEU-Th cycle fuel elements, with only slight modifications in size and configuration to accomadate for the differences in the fuels (SAI 1978).

### 1.1.2 Fuel Particle

The fuel consists of BISO- and TRISO-coated fuel kernels. BISO coating, which consists of two layers, namely low-density, pyrolytic carbon buffer and high-density isotropic pyrolytic carbon, is applied to the fertile particles, consisting of spherical $ThO_2$ of about 500-micron diameter. TRISO coating, which consists of three layers, namely a low-density pyrolytic carbon to act as a buffer, silicon carbide, and high-density isotropic pyrolytic carbon to retain the fission products, is applied to the fissile particles, consisting of spherical highly enriched uranium dicarbide ($UC_2$) kernels of about 200-micron diameter. The fuel compacts consist of the fissile and fertile kernels described above, uniformly dispersed in a small graphite cylinder (SAI 1978).

## 1.2 Process Description

HTGR fuel consists of tiny, spherical, carbon-coated, enriched $UC_2$ and $ThO_2$ particles, blended together and formed into rods by means of a matrix filler and binder. These fuel rods, along with BC rods, are inserted into holes machined in graphite blocks and are subsequently sealed by the addition of cemented graphite plugs to make a finished fuel element. The basic steps in fabricating HTGR fuel are illustrated in Figure 2.

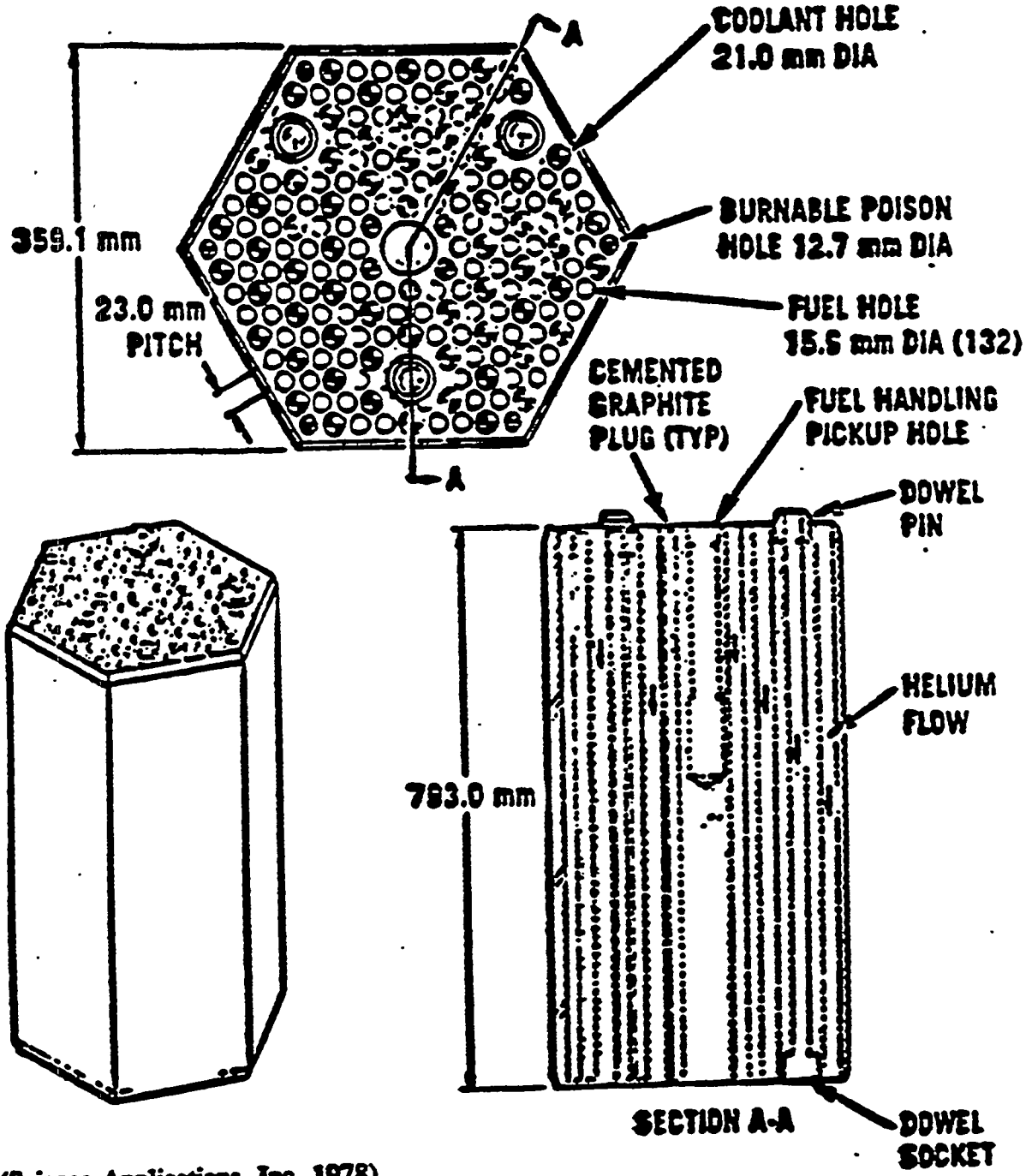
The primary steps, which are discussed below, in the manufacture of HTGR fuel assemblies are:

(1) particle production;
(2) fuel rod fabrication; and
(3) element manufacture.

---

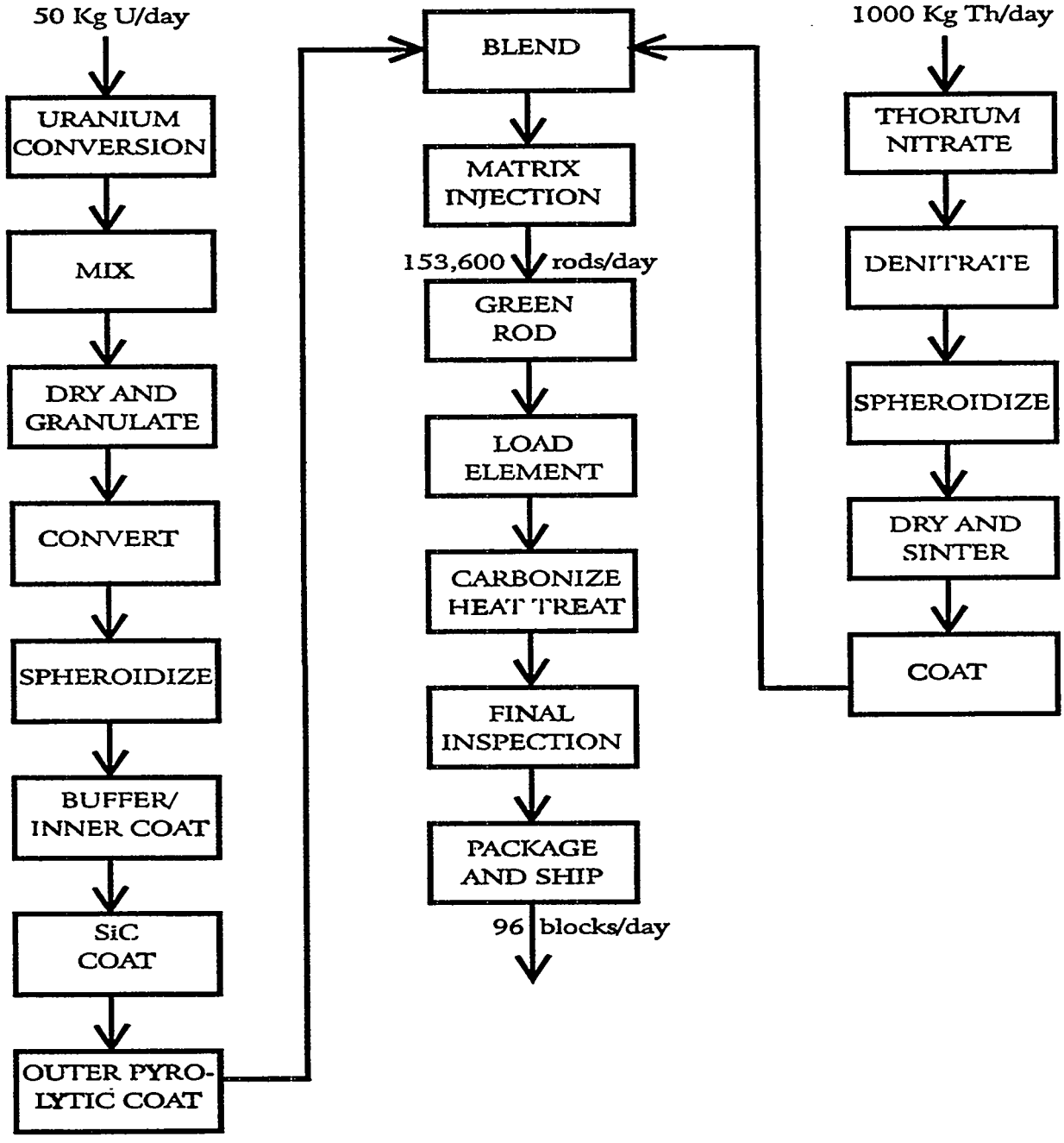
[1]In the commercial 1160 MWe design that was offered by General Atomic, there are eight fuel elements in each column, and a total of 493 columns in the reactor core.

**Figure 1. HTGR Standard Fuel Element**




*(Science Applications, Inc. 1978)

**Figure 2. Basic Steps in HTGR Fuel Fabrication***




*(Science Applications, Inc. 1978)

## Particle Production

HTGR particle production is comprised of: (1) kernel production and (2) spheroidization.

### Fissile Particle Production

The process starts with highly enriched $UF_6$, which is fed into a $UO_2$ conversion unit (see Information Packages 6-9). The resulting $UO_2$ is mixed with carbon flour and an ethylene binder using a batch process to form a slurry. The slurry is then oven-dried and milled to sand-sized particles. The oxides are converted to carbides in a vacuum heating step. As a result of vacuum heating, the oxygen is replaced by carbon, and carbon monoxide (CO) and carbon dioxide ($CO_2$) are released. Small particles of uranium carbide are fed through a furnace (operating in excess of the melting point of the uranium carbide) to form tiny microspheres. The spherical shape of the kernels is a result of surface tension.

In a fluidized bed furnace, the BISO and TRISO coatings are applied to the microspheres, forming the primary barrier to fission gas release. Spheroidized kernels are introduced into a high temperature furnace and levitated by a stream of inert gas. A mixture of hydrocarbons is introduced into the stream and the dissociation produced by the high temperature results in deposition of pyrolytic carbon layer on the particles. The coated kernels are then transferred to a second furnace, where a silicon carbide layer is deposited. Finally, an additional layer of pyrolytic carbon is added in a third furnace. Fissile particle production for the LEU cycle would be very similar to that for the HEU-Th cycle, with the major difference being in the enrichment of the feed $UF_6$.

### Fertile Particle Production

The $ThO_2$ kernels are fabricated by a gel process, which begins with dissolving thorium nitrate in water. The solution reacts with a stream to form a fine $ThO_2$ powder, which is dispersed into dilute nitric acid. After concentration and addition of an organic gel to control the viscosity, the $ThO_2$ suspension is fed through nozzles which are vibrated to facilitate the formation of regularly sized spheres. The spheres fall through ammonia ($NH_3$) gas, and then through a column of an ammonium hydroxide solution. The wet spheres are then collected, dried and sintered at 1,200°C. The production consists of dense $ThO_2$ kernels with a narrow-size distribution. The kernels receive a double coating of pyrolytic carbon with a process similar to the one used for the fissile particles, but with no silicon carbide applied. Fertile particle production for fuel cycles using depleted uranium as fertile fuel would probably be similar to fissile particle production, but would use the same coating described for $ThO_2$ particles.

Fuel Rod Fabrication

In fuel rod fabrication, the coated particles are positioned in a multi-cavity injection mold where a heated mixture of petroleum pitch and graphite powder are injected into the mold, filling the void space around the particles. When cooled, the "green" rods are ejected from the molds as right circular cylinders. The rods are packed in finely ground aluminum oxide and heated to 800°C to carbonize the petroleum pitch. The carbonized rods are then treated with hydrogen chloride (HCl) gas at an elevated temperature to leach exposed uranium and thorium from the rods. They are then heated to 1,700°C to remove residual HCl and improve heat transfer characteristics of the rods.

Fuel Element Manufacture

In fuel element manufacture, fuel rods and BC rods are loaded into their respective channels, which are then sealed by insertion of graphite plugs coated with a high-temperature graphite cement. The element is then heated to cure the cement. The completed fuel element is loaded into a government-approved shipping container, and the container is placed in storage until it is shipped to a reactor site.

Reprocessing

After irradiation, the fuel elements are removed, crushed, and burned. During combustion, the BISO particles lose their coatings and become oxide spheres. The TRISO particles lose their outer coating, but the silicon carbide and inner graphite coatings remain intact. These two particles are then separated by elutriation with carbon dioxide gas. The BISO particles are processed to recover bred, fissile material as well as remaining fertile material. The TRISO particles are processed to separate remaining fissile $^{235}U$ from fission product wastes (Benedict, M., et al 1981).

## 1.3 Input Materials

The primary input materials required for HEU-Th cycle HTGR fuel assembly production are uranium and thorium. The daily material flow rates of uranium and thorium corresponding to an HTGR design with a conversion ratio of 0.63 for a fuel production facility capable of producing six 1160 MWe reactor cores per year are listed in Table 1[2]. A facility such as this could support an HTGR population of eighteen 1160 MWe reactors.

[2]Fuel fabrication facility described in Science Applications, Inc. 1978.

**Table 1. Input Material Flow Rates for HTGR Fuel Fabrication Facility[a]**

| Material | Requirement |
|---|---|
| 93% Enriched Uranium | 50 kg/ day |
| Thorium | 1000 kg/ day |

[a](Science Applications, Inc. 1978).

1.4 Products

The daily product flow rates for an HEU-Th cycle HTGR production facility of the type described in Section 1.3 are listed in Table 2.

**Table 2. Product Flow Rates for HTGR Fuel Fabrication Facility[a]**

| Product | Number Produced |
|---|---|
| Fuel Rods | 153,600/ day |
| Fuel Assemblies | 96/ day |

[a](Science Applications, Inc. 1978).

The waste streams from the HTGR fuel fabrication process are discussed in A.3 and B.1. The amount of wastes produced is unknown at this time.

1.5 Depleted $UF_6$ Consumption

In order for depleted uranium to be used in HEU-Th cycle HTGR fuel fabrication, it must first be heavily re-enriched. Assuming that the entire depleted $UF_6$ stockpile is enriched from 0.25% $^{235}U$ to 93% $^{235}U$, with a tails assay of 0.1%, a single facility of the type described in Section 1.3 could be supported for over 30 years while consuming only 600 of the 560,000 metric tons of depleted $UF_6$.

The assumptions for depleted $UF_6$ consumption in one approach to the LEU cycle are: (1) the

depleted uranium stockpile is re-enriched to 15% for use in the fissile particle production, (2) the remaining 0.1% tails are used in the fertile particle production in place of the thorium, and (3) the material weight requirements for the LEU fissile and fertile particle production are the same as in the HEU-Th case above. In this scenario, almost 600 metric tons of the depleted $UF_6$ stockpile would be consumed annually in the reference facility. Another approach to the LEU cycle is to use depleted uranium in fertile particle production only, using enriched natural uranium as the driver fuel. This approach would consume 540 metric tons of depleted $UF_6$ annually in the reference facility.

Depleted $UF_6$ consumption is not limited to the scenarios discussed above. Other scenarios could include blending of depleted uranium with HEU or recycled $^{233}U$ to fulfill the 5-15% enrichment requirement for the LEU cycle.

# EVALUATION FACTORS

## A. ENVIRONMENT, SAFETY, AND HEALTH

The construction and operation of a HTGR fuel fabrication plant in the United States would be regulated by 10 CFR Part 40, "Domestic Licensing of Source Material." Environment, safety, and health issues would be covered by these and other Federal, State, and local regulations.

### A.1 Operations, Handling, Storage, Transportation, and Disposal

Materials that would be used in the fabrication of HTGR fuel are covered by Federal, State, and local regulations involving process safety, transportation, handling, storage, and disposal.

Uranium is toxic to the kidneys and high exposure to soluble compounds can result in renal injury. A concentration of about 1 μg/g of kidney tissue has been used as a guideline for controlling the chemical toxicity of uranium. In occupational situations, where inhalation is the primary concern and radiation dose limits are high, chemical toxicity is limiting for more soluble compounds and radiotoxicity is limiting for the insoluble compounds (Hertzler and Nishimoto 1994).

Nuclear Regulatory Commission (NRC) regulations (10 CFR 20.1301) require that the total effective dose equivalent for releases related to routine operations (i.e., for a generic HTGR fuel fabrication plant) should not exceed 1 milliSievert (mSv) per year. In addition, Environmental Protection Agency (EPA) regulations (40 CFR Part 190) require that for routine releases to the general environment, the annual dose equivalent should not exceed 0.25 mSv to the whole body, 0.75 mSv to the thyroid, and 0.25 mSv to any other organ. For releases to the atmosphere, EPA regulations (40 CFR Part 61) require that the annual effective dose equivalent should not exceed 0.1 mSv.

#### Transportation

In general, the transportation of radioactive materials is regulated under 10 CFR Part 71 (Packaging and Transport of Radioactive Material) and 49 CFR.

#### Disposal

The primary disposal concerns with HTGR fuel fabrication result from the waste streams of the $UO_2$ conversion process discussed in B.1 (see Information Packages 6/7/8 and 9).

Disposal of high-level radioactive materials, such as commercial spent nuclear fuel, is regulated

under 10 CFR Part 60 (Disposal of High-Level Radioactive Wastes in Geologic Repositories) and 40 CFR Part 191 (Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes).

## A.2 Siting Factors

Siting standards for a HTGR fuel fabrication plant are covered in NRC licensing regulations possession and use of source material. According to 10 CFR Part 40.31, to obtain a license to possess and use source material, such as depleted uranium, an application must be filed with the NRC at least 9 months prior to the start of construction, accompanied by any Environmental Report required pursuant to 10 CFR Part 51. The Environmental Report must describe the impact to the environment from construction, operation, and decommissioning of the plant, including the status of compliance with all applicable Federal, State, regional, and local regulations for environmental protection, including zoning and other land-use restrictions. Under 10 CFR Part 40, the license application for possessing and using source material must include installation information pursuant to 10 CFR Part 75.11 which, for siting, includes identifying the geographic location of the plant.

Land requirements for a HTGR fuel fabrication plant are unknown at this time. However, based on plans for a HTGR fabrication facility in Youngsville, NC, approximately 156,000 square feet of floor space would be required (GA Technologies 1982).

## A.3 Public and Worker Safety

The common method for fabricating HTGR fuel uses the wet ammonium diuranate (ADU) process (see Information Package 7). Many of the process hazards are similar to those identified for ADU. The primary chemicals associated with the HTGR fuel fabrication process include:

- Ammonia ($NH_3$): Used in the ammonia vaporizer.
- Nitric acid ($HNO_3$): Used in the wet uranium recovery process.
- Hydrogen ($H_2$): Used in the fuel particle coating process.
- Hydrogen fluoride (HF): By-product of the $UF_6$ conversion process.
- Nitrogen ($N_2$): Used in fuel fabrication.
- Uranium hexafluoride ($UF_6$): Used as the feed-stock for producing $UO_2$.

- Argon (Ar): Used in the fuel fabrication process.

- Hydrogen chloride (HCl): Used in the fuel rod fabrication process.

Public and worker safety would be addressed by the material license for operating a HTGR fuel fabrication plant. In addition, some of the unit operations are similar to those at other commercial nuclear fuel fabrication plants.

## B. WASTE MANAGEMENT

### B.1 Waste Storage, Transportation, Treatment or Disposal

Waste streams from $UO_2$ conversion processes are addressed in Information Packages 6/7/8 and 9. There do not appear to be any unique waste management concerns with operation of a HTGR fuel fabrication plant.

### B.2 Recycling Potential

During irradiation in an HEU-Th cycle HTGR, about three-fourths of the fissile $^{235}U$ is consumed, leaving only fission products and uranium with an isotopic content of 20% fissile $^{235}U$, 25% $^{238}U$, and 55% $^{236}U$. In the fertile particles, about 8% of the fertile thorium is converted to fissile $^{233}U$, some of which is fissioned. The percentage of fissile materials remaining after irradiation gives the HTGR fuel cycle a high potential for recycling. In comparison with a light water reactor (LWR) with plutonium recycle, the HTGR with $^{233}U$ recycle requires about the same amount of separative work, but uses 35% less natural uranium (Benedict, M., et al 1981).

## C. COSTS

### C.1 Capital Costs, Annual Operations and Maintenance Costs

No data was available on the construction costs for an HTGR, however, the unit cost assumptions per fuel element for a 2240 MWt HTGR fuel cycle are listed in Table 3.

**Table 3. Unit Cost Assumptions for 2240 MWt HTGR Fuel Cycle***

| Fuel Cycle Activity | Cost ($/ Fuel Element) |
|---|---|
| Fabrication of Elements | 15,130 |
| 10-yr At Reactor Storage | 2,480 |
| Shipment to Reprocessing Plant | 3,910 |
| Reprocessing | 19,000 |
| Shipment of HLW[3] to Repository | 160 |
| HLW Disposal | 5,050 |
| Total | 45,730 |

*(GA Technologies 1982).

C.2 Product Value/Facility Salvage

Product value/ facility salvage data are not available at this time.

C.3 Cost Avoidance Through By-Product Sales

The sale of the HF produced in the $UF_6$ conversion process to the commercial market is discussed in Information Packages 1 and 2. The potential for further cost avoidance through by-product sales is unknown at this time.

## D. TECHNICAL MATURITY

The HTGR fuel fabrication process is a standard industrial practice. General Atomics has produced commercial grade HTGR fuel in a fabrication plant located in La Jolla, CA. As such, the technology is considered mature, and would probably not require any new design work.

[3]High Level Waste

The Ft. St. Vrain HTGR is now being decommissioned. It was the only large, commercially operated HTGR in the U.S. The HTGR has been proposed in various forms for several purposes, but not yet built. The only gas reactors that have been used on a large scale have been in Great Britain and France. These reactors use a metal rather than a carbide fuel.

## E. SOCIOECONOMICS

### E.1 Employment

Actual employment data for a HTGR fuel fabrication plant are not available at this time.

### E.2 Public Acceptance

No formal evaluation of public acceptance has been made at this time.

### E.3 Local/Regional Development

Local and regional development resulting from construction and operation of a HTGR fuel fabrication plant cannot be measured at this time.

## REFERENCES

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U.S. Code of Federal Regulations 10 Part 51. 1994. *Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions.*

U.S. Code of Federal Regulations 10 Part 75. 1994. *Safeguards on Nuclear Material - Implementation of US/IAEA Agreement.*

# INFORMATION PACKAGE
# G1

# HEU Blending Using Depleted $UF_6$

This information package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on depleted $UF_6$ technologies or applications currently under consideration by the Department. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; they are intended to provide sufficient information to assist the Independent Technical Reviewer.

# *HEU BLENDING USING DEPLETED $UF_6$*

## 1. OVERVIEW

This information package briefly describes the use of depleted uranium hexafluoride (UF6) to blend highly enriched uranium (HEU) into low enriched uranium (LEU) for use in nuclear power plants. It also provides data on environment, safety, and health; waste management; cost; technical maturity; and socioeconomics, to assist in the evaluation of Request for Recommendation (RFR) submittal from M. Strauch (RFR No. 2).

### 1.1 Process Description

The process for blending depleted $UF_6$ (with an assay of <0.71% uranium-235 [$^{235}U$] isotope) with HEU (with assays of >20% $^{235}U$) is a multi-part process. First the HEU must be converted from a metal to an oxide ($U_3O_8$). The assay of this oxide must be verified and then the material must be converted to $UF_6$ using a fluorination process. The high-assay $UF_6$ is then blended with the depleted $UF_6$ material to produce a product with 3-5% assay $^{235}U$. Figure 1 provides a diagram of the process.

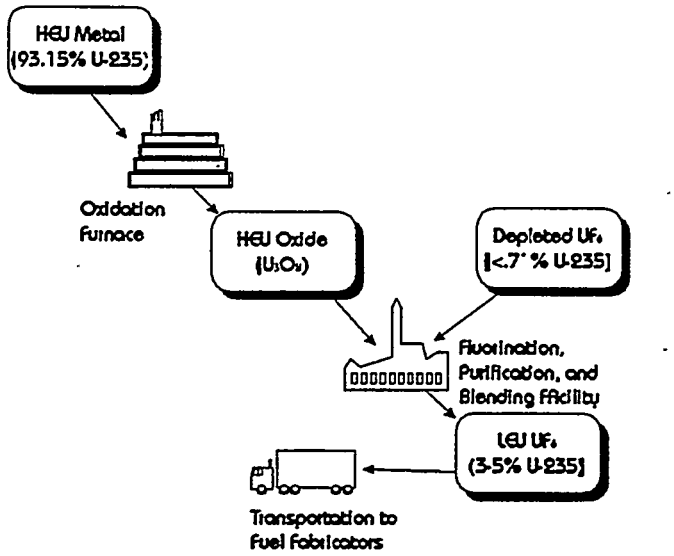


*Figure 1. Example HEU Metal to LEU $UF_6$ Blending Flow Diagram*

### 1.2 Input Materials

The primary input materials for the HEU blending process are depleted $UF_6$ and HEU metal. A declassified inventory of 258.8 metric tons (MT) of HEU with assays greater than 20% was released by the Department of Energy (DOE 1995). Because the actual assays of the HEU held

by the US government are classified, HEU is considered to have an assay of more than 20% $^{235}U$. For the purposes of this document, the commonly accepted assays of 50% and 93.15% $^{235}U$ will be used. The inventory of depleted $UF_6$ reported by the Department of Energy is approximately 560,000MT. The quantities of HEU and depleted $UF_6$ required for a blending process that uses only depleted $UF_6$ to blend are provided in Table 1.

**Table 1. Metric Tons of HEU (MT HEU) Assumed to be Available for Blending**

| Type of HEU | 100 MT HEU | 200 MT HEU | 300 MT HEU | Amount $^{234}U$ in Product (in mg $^{234}U$/g $^{235}U$) |
|---|---|---|---|---|
| 93.15% $^{235}U$ | [illegible] | [illegible] | [illegible] | 10,600 |
| 50% $^{235}U$ | [illegible] | [illegible] | [illegible] | 7,100 |
| | Metric tons of depleted $UF_6$ (MT DU) needed to blend with given amount of HEU | | | |

## 1.3 Products

The product of the HEU blending process is LEU. As can be seen from Table 1, the amount of $^{234}U$ in the LEU product exceeds 10,000mg of $^{234}U$ per 1g of $^{235}U$ by 6%, which, according to the American Society for Testing and Materials (ASTM) specification C996-90, is the limit for LEU. Therefore, to be usable, product derived from HEU using only depleted $UF_6$ would need to be blended with an increase in the fissile material ($^{235}U$). For example, if an assay of 3% is desired, an actual assay of 3.18% (6% over the desired) would be necessary to compensate for the 6% extra content of $^{234}U$. DOE has come to the conclusion that in order to blend HEU of 93.15% assay to LEU that meets the ASTM specification for $^{234}U$, it would be necessary to blend the HEU with depleted $UF_6$ to an assay of 19%, then blend the resulting 19%-assay LEU with a slightly enriched LEU of 2.2% assay (DOE 1995). The current stockpile of LEU with 2.2% assay held by DOE is of an insufficient quantity to blend all of the HEU using this method (DOE 1995).

## 1.4 Depleted $UF_6$ Consumption

Table 1 provides consumption levels for depleted $UF_6$ when used to blend with either 50%- or 93.15%-assay HEU. When the 258.8 MT of HEU is of 50% assay, the amount of depleted $UF_6$ necessary to blend to LEU would be ~2,820 MT. If the HEU to be blended were of an assay of 93.15%, the amount of depleted $UF_6$ necessary for blending would be ~5,460 MT. The amount of depleted $UF_6$ would be less than 10% of current inventory.

## *EVALUATION FACTORS*

## A. ENVIRONMENT, SAFETY, AND HEALTH

The construction and operation of a facility to convert HEU metal into $UF_6$ and then blend it with the depleted $UF_6$ would be regulated by 10 CFR Part40, *Domestic Licensing of Source Material*; 10 CFR Part70, *Domestic Licensing of Special Nuclear Material* (SNM); 10 CFR Part73, *Physical Protection of Plants and Materials*; and 10 CFR Part74, *Material Control and Accountability of Special Nuclear Material*. Environment, safety, and health would be covered by these and other federal, state, and local regulations.

### A.1 Operations, Handling, Storage, Transportation, and Disposal

Materials that would be used in the blending of HEU with depleted $UF_6$ to produce LEU are covered by federal, state, and local regulations involving process safety, transportation, handling, safeguards and security, storage, and disposal.

### A.2 Siting Factors

Siting standards for depleted $UF_6$ blending plants are covered in Nuclear Regulatory Commission (NRC) licensing regulations concerning the use and possession of source material and SNM. According to 10 CFR40.31, to obtain a license to possess and use source material, such as depleted $UF_6$, an application must be filed with the NRC at least nine months prior to the start of construction, along with an environmental report as specified in 10 CFR Part 51. In addition, a license to possess SNM is required pursuant to 10 CFR Part 70. The license application must include installation information required in 10 CFR 75.11, including identification of the geographic location of the plant.

Land requirements for a depleted $UF_6$ blending plant are unknown. There is no such plant currently in existence. However, portions of gaseous diffusion plant (GDP) sites adjust assays in cylinders. The Y-12 plant has processing capabilities to blend HEU metal to LEU metal. The Portsmouth Gaseous Diffusion Plant can blend $UF_6$, and two other DOE sites have limited capabilities.

### A.3 Public and Worker Safety

The radiological hazards associated with depleted uranium, regardless of form, are primarily due to alpha particle emission, meaning that the uranium would have to be ingested or inhaled to present a health hazard. Historically, the chemical toxicity of uranium has been the primary concern for occupational exposure to depleted uranium, for which Occupational Safety and Health Administration standards exist (Hertzler et al. 1994).

## B. WASTE MANAGEMENT

There do not appear to be any unique waste management concerns with the operation of a depleted $UF_6$ blending plant because of the similarity between such a plant and the GDPs currently in operation. Wastes from the blending process (like wastes from the enriching process) are classified as low-level waste. As previously stated, $UF_6$ is a volatile substance, that when exposed to moisture in ambient air, forms HF acid and $UO_2F_2$. These reaction products are hazardous wastes regulated under the Resource Conservation and Recovery Act (RCRA).

## C. COSTS

### C.1 Capital Costs, Annual Operations, and Maintenance Costs

Capital costs for construction of a depleted $UF_6$ blending plant have been estimated by both DOE (MMES 1991) and private industry (DOE 1995). The estimated cost for construction of such a plant by DOE is $100 million, and the estimates for private industry are $30-$100 million. Total life-cycle operating costs, as estimated by DOE, are ~$262 million.

### C.2 Product Value/Facility Salvage

According to current market values, one kilogram of 50%-assay HEU has a value of ~$8,000-$9,800, once blended to commercial fuel levels (DOE 1995). Assuming these figures and a 50% assay for the HEU, a total gross value of the 258.8 MT of HEU is ~$2 -$2.5 billion.

### C.3 Cost Avoidance through By-Product Sales

It has been estimated that the cost to blend 50%-assay HEU to LEU would be ~$2,000 per kilogram (DOE 1995). Using this figure and those in section C.2, the total net value of the 258.8 MT of HEU is ~$1.5 billion-$2 billion.

## D. TECHNICAL MATURITY

The process of blending depleted $UF_6$ with HEU is not a current industrial practice, but would be similar to existing assay adjustment operations at the GDPs. (See section A.4.)

## E. SOCIOECONOMICS

### E.1 Employment

Actual employment data for a depleted $UF_6$ blending plant are not available at this time.

E.2 Public Acceptance

No formal evaluation of public acceptance has been made at this time.

E.3 Local/Regional Development

Local and regional development resulting from the construction and operation of a depleted $UF_6$ blending plant cannot be measured at this time.

## REFERENCES

Letter from M. Strauch to C. Bradley, Jr., DOE. Request for Recommendation#2.

Martin Marietta Energy Systems, Inc. 1991. *Feasibility Study for High Assay Utilization Facility.* POEF-E-447. Oak Ridge, TN

U. S. Department of Energy. 1995. *Comprehensive Uranium Inventory Report (draft).* Washington, DC.

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U.S. Code of Federal Regulations 10 Part 40. 1994. *Domestic Licensing of Source Material.*

U.S. Code of Federal Regulations 10 Part 51. 1994. *Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions.*

U.S. Code of Federal Regulations 10 Part 70. 1994. *Domestic Licensing of Special Nuclear Material.*

U.S. Code of Federal Regulations 10 Part 71. 1994. *Packaging and Transportation of Radioactive Material.*

U.S. Code of Federal Regulations 10 Part 73. 1994. *Physical Protection of Plants and Materials.*

U.S. Code of Federal Regulations 10 Part 74. 1994. *Material Control and Accounting of Special Nuclear Material.*

# INFORMATION PACKAGE
# H1

# DU Re-Enrichment: AVLIS Technology

This Information Package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on Depleted $UF_6$ technologies or applications currently under consideration by the Department of Energy. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; it is intended to provide sufficient information to assist the Independent Technical Reviewer.

# DEPLETED URANIUM RE-ENRICHMENT: AVLIS TECHNOLOGY

## 1. OVERVIEW

A reuse option for depleted uranium is re-enrichment in an Atomic Vapor Laser Isotope Separation (AVLIS) facility. AVLIS employs lasers to separate the isotopes of uranium into two streams: one enriched in $^{235}U$ and one depleted in $^{235}U$. Full recovery of the $^{235}U$ in the existing depleted uranium stockpile (tails) could equate to roughly 1000 reactor-years of nuclear fuel consumption. Re-enrichment in an AVLIS facility was recommended in responses to the Request for Recommendation from Idaho National Engineering Laboratory (RFR #4), the Ohio Valley Regional Development Commission (RFR #11), and GenCorp Aerojet (RFR#15).

Based on assessment of the economic viability of AVLIS commercialization, the United States Enrichment Corporation (USEC) decided in 1994 to proceed with commercializing the AVLIS technology. An AVLIS tails stripping plant would have the same basic design as a plant enriching natural uranium feed. The revenues from a tails stripping plant are less than those from the same plant operating on natural feed, and the revenues for tails stripping are particularly sensitive to the price of uranium ore (yellowcake).

### 1.1 AVLIS Process Description*

An AVLIS plant is composed of two distinct systems, the separator system and the laser system, as represented in Figure 1. The AVLIS process feed to the separator unit is uranium metal alloyed with iron. The uranium is electron beam evaporated, and the desired $^{235}U$ isotope in the flowing atomic vapor stream is selectively excited and ionized by the laser beams. The $^{235}U$ ions are electrically extracted and, along with some neutral vapor, condense on the enriched product collector. The unaffected neutral vapor stream (depleted in $^{235}U$) condenses on the tails collector. The laser system provides the tunable, high average power visible light for the process. Dye lasers convert the fixed frequency output of copper lasers into the process light.

### 1.2 Uranium Flows and Enrichment Capacity

The reference AVLIS plant, as described in the Conceptual Design Report (CDR) prepared for the Department of Energy (LLNL 1991), operates on natural uranium feed and contains six separator lines (a separator line is a string of independent separator units). A preliminary assessment has been made for a plant of this size and design operating on a depleted uranium feed. The analysis

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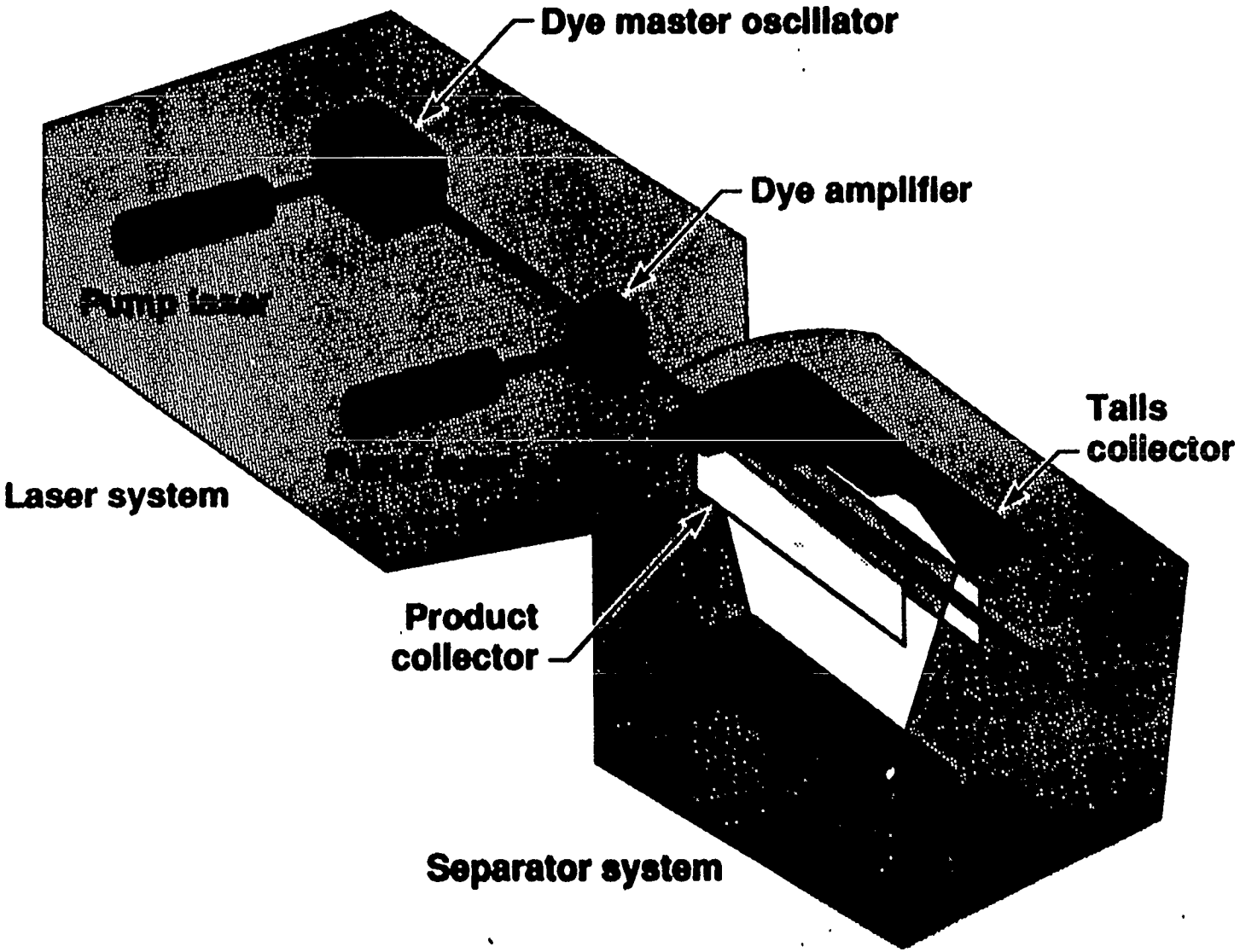
* Separative work to enrich natural assay (0.711% $^{235}U$) uranium to 3.6% $^{235}U$ with a 0.28% $^{235}U$ tails assay was evaluated.

# The basic AVLIS systems




30-01-0282-03288

FIGURE 1

assumed a feed assay of 0.30% $^{235}U$ and an average enriched product assay of 3.6% $^{235}U$. The annual rates for such a plant are given in Table 1.

**Table 1 Annual Plant Rates**

| Quantity | Rate |
|---|---|
| Feed (0.3% $^{235}U$) | 9.4 million kg/y (as U) |
| Product (3.6% $^{235}U$) | 0.67 million kg/y (as U) |
| Tails (< 0.1% $^{235}U$) | 8.7 million kg/y (as U) |
| Separative Work | 3.16 million SWU/y |

### 1.3 Principal Revenues

The principal revenues are the salable separative work and the savings in natural assay $UF_6$, that annually amounts to about 5 thousand tonnes (as U).

### 1.4 Depleted $UF_6$ Stockpile Consumption

Based on the annual feed rate of metal to the conceptual tails stripping plant (9.4 million kilograms, or 9,400 tonnes), the annual consumption of depleted $UF_6$ (metal precursor) from the existing stockpile is approximately 14 million kilograms (14,000 tonnes).

### 1.5 Disposition of AVLIS Tails

The depleted uranium tails (<0.1% $^{235}U$) after AVLIS processing will require eventual disposition (greater than 90% of the input uranium will appear as tails material). The alloy tails material can be converted into oxide or cast into metal ingots. Costs for both options are estimated to be less than the cost of converting depleted $UF_6$ to the oxide. If acceptable, storage or disposal in the ingot form (suitably contained) would be preferable, due to the much greater density of the alloy compared to compacted oxide.

## A. ENVIRONMENT, SAFETY, AND HEALTH (ES&H)

The licensing of a U-AVLIS plant by the Nuclear Regulatory Commission (NRC) is expected to be governed by 10 CFR Part 70, *Domestic Licensing of Special Nuclear Material*, which covers nuclear safety and safeguards. NRC would also be the lead agency for compliance with the National Environmental Policy Act and would prepare an Environmental Impact Statement per 10 CFR Part 51.

Due to the lower radioactivity of the depleted uranium feedstock (about 50-60% of that of natural uranium), the radiological hazards related to plant operations are somewhat less than those for a U-AVLIS plant that enriches natural uranium. Apart from this, there are no apparent, significant differences in ES&H plant as compared to those for the U-AVLIS plant projects previously evaluated by DOE

(LLNL 1991). These evaluations concluded that a large capacity U-AVLIS plant could be built and operated with low safety risk and minor environmental impacts. The principal safety concerns are prevention of accidental criticality and protection of workers from exposure to airborne uranium oxide particulates in uranium processing areas. These hazards can be prevented or controlled by the application of conventional techniques.

Use of the AVLIS technology for re-enrichment of depleted uranium would conserve a limited natural resource (natural uranium) and reduce the environmental impacts associated with its mining and milling.

## B. WASTE MANAGEMENT

The primary radioactive waste stream generated by a U-AVLIS enrichment plant is solid low-level radioactive wastes (uranium-contaminated metals, ceramics, filters, etc.) stemming from uranium separator refurbishment operations and contamination control activities. No significant radioactive liquid waste streams or mixed radioactive/hazardous waste streams are generated. The principal hazardous waste stream generated by the plant is degraded optical dye dissolved in ethanol, which is removed from the dye laser system and disposed after recovery of about 90% of the ethanol content via distillation. Conventional waste streams will include cooling tower blowdown and sanitary sewage.

## C. COSTS

Based on the Conceptual Design Report prepared for DOE (LLNL 1991), the estimated capital cost for a 6-line AVLIS plant (enrichment only) is $1.2 billion (FY93). This assumes commercial deployment and NRC licensing. The estimated annual operating cost is $147 million. The total annual revenues are projected to be roughly $600 million.

## D. TECHNICAL MATURITY

The AVLIS technology has not been commercially deployed. The U- AVLIS technology is in the final stages of engineering and has been successfully tested at full specific scale.

# E. SOCIOECONOMICS

## E.1 Employment

Based on the Conceptual Design Report prepared for DOE, the estimated employment level is about 1100 persons.

## E.2 Public Acceptance

No formal evaluations have been made. Some limited public resistance to the siting and licensing of a U-AVLIS enrichment plant could be expected as for any nuclear fuel cycle facility. However, a U-AVLIS plant is likely to be accepted by potential host communities because of its low environmental impacts and significant employment opportunities. The state-of-the-art technology that would be used in such a plant would provide significant regional opportunities for spin-off economic growth in several high technology areas.

## E.3 Local/Regional Development

Based on the projected employment level and capital investment, the deployment of an AVLIS capability would be expected to have a favorable economic impact.

## REFERENCES

GenCorp Aerojet, 1995, Letter to LLNL, Subject: Request for Recommendations (RFR) for Depleted Uranium Hexaflouride ($dUF_6$) Management Program.[1]

Lawrence Livermore National Laboratory, 1991, *Conceptual Design Report for U-AVLIS Production Plant*, LP-91-142, multiple volumes (draft, restricted from public release).

Additional unrestricted information, derived from the above and other documentation, will be provided upon request.

Idaho National Engineering Laboratory, 1994, Letter to DOE, Subject: Federal Register Request for Recommndations, WJQ-67-94.[2]

Ohio Valley Regional Development Commission, 1994, Letter to LLNL, no subject.[3]

[1] RFR document #15
[2] RFR document #4
[3] RFR document #11

# INFORMATION PACKAGE
# H2

# Uranium Re-Enrichment: Centrifuge

This information package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on depleted $UF_6$ technologies or applications currently under consideration by the Department. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; they are intended to provide sufficient information to assist the Independent Technical Reviewer.

# URANIUM RE-ENRICHMENT: CENTRIFUGE

## 1. OVERVIEW

This information package describes re-enriching uranium with depleted uranium hexaflouride ($UF_6$) via a centrifuge process. It also provides supplemental data on environment, safety, and health; waste management; costs; technical maturity; and socioeconomics, to assist in the evaluation of Request for Recommendation submittal number 11 (Carter 1994).

This information package is based on information contained in the *Final Environmental Impact Statement for the Construction and Operation of the Claiborne Enrichment Center (CEC), Horner, Louisiana,* prepared by the U.S. Nuclear Regulatory Commission (NRC 1994). At this time, a definite decision to build the CEC centrifuge plant in Louisiana has not been made. The centrifuge enrichment process has been a viable process, used predominantly by other countries, for many years. Presently, other centrifuge plants exist outside the U.S. that could re-enrich uranium using the depleted $UF_6$ (NRC 1994).

### 1.1 Process Description

The Louisiana Energy Services, (LES) proposed Claiborne Energy Center (CEC) centrifuge enrichment facility is based on the use of a very simple process and a technically proven piece of equipment, the "gas centrifuge." The gas centrifuge is basically a cylindrical vessel with an external electric motor (variable speed) which drives an internal rotor. About 1,000 centrifuge vessels are connected together in a series/parallel piping and valving arrangement called a cascade.

The enrichment process in a gaseous diffusion plant (GDP) requires many stages in a cascade to achieve an enriched product. The centrifuge process is similar, bu requires fewer number stages in series. Most stages of both processes are run at pressures below atmospheric conditions. The series/parallel piping arrangement has two main process flow streams, one which carries an ever-increasing by enriched product, and; the second, which is being depleted of the natural uranium-235 isotope (from the $UF_6$ feed) as it proceeds through the centrifuge cascade (NRC 1994).

The enrichment process in the gaseous centrifuge vessel is mainly possible because of the mass (centrifugal force) differences in the isotopes of U-235 and -238. The mass difference in turn causes the isotopes of U-235 and U-238 to vary at different locations in the centrifuge. The enriched gas is withdrawn at the top of the rotor center post, and the depleted gas is withdrawn at the bottom. Also, cooling coils located at the top and bottom of the rotor remove heat and provide a temperature gradient which plays an additional role, along with the centrifugal force, in producing the isotopic separation. The process piping exits the centrifuge vessels at these collection regions, and the product then flows on to another downstream centrifuge in the cascade system until it is withdrawn at the product discharge end of the process (NRC 1994).

## 1.2 Depleted Uranium Hexafluoride as Feed Material

The CEC centrifuge plant enrichment process was designed to accept $UF_6$ as the feed material. The feed (yellow cake material) has a natural enrichment of 0.7 percent U-235. The centrifuge process, like the gaseous diffusion process, requires a feed stream and discharges two process streams, one being an enriched (U-235) $UF_6$ stream and the other being a depleted $UF_6$ hexafluoride (DUF) stream (NRC 1994). The depleted $UF_6$ by-product produced in the gaseous diffusion plants being considered for refeed in the centrifuge plant is typically stored with an assay of about 0.2 - 0.3 percent U-235. Very little of the depleted $UF_6$ feed inventory would be removed as product (enriched uranium), and the depleted $UF_6$ inventory would be reduced only slightly, i.e., 3 percent (Hertzler March 1994). It is estimated that if 560,000 tons of DUF were processed, the DUF inventory would be reduced by 29,000 tons. The issue of final consumption or disposition of depleted $UF_6$ would remain.

# EVALUATION FACTORS

## A. ENVIRONMENT, SAFETY, AND HEALTH

The radiological hazards from depleted $UF_6$ are primarily due to alpha particle emission. This means that the internal radiation dose from ingestion or inhalation of uranium compounds is the limiting hazard under almost all circumstances (Hertzler 1994).

Depleted $UF_6$, when released to the atmosphere, reacts with moisture in the air to form uranyl fluoride ($UO_2F_2$) and hyrdrofluoric acid (HF). The HF is a corrosive and irritating acid vapor that can severely harm the lungs and skin if exposed to sufficient concentrations. The $UO_2F_2$ forms a particulate, which is very soluble in the lungs and can be carried away by the wind and deposited on the ground.

### A.1 Operations, Handling, Storage, Transportation, and Disposal

Some of the ES&H concerns related to centrifuge facilities include the following:

- Production of gaseous, liquid, and solid waste streams. Each stream could contain small amounts of hazardous and radioactive compounds, either alone or in a mixed form.
- Routine uranium releases to the atmosphere from the CEC plant were estimated to be 120 mCi annually.
- Liquid effluents would be regulated by a National Pollutant Discharge Elimination System (NPDES).

Releases of depleted $UF_6$ from process connections and equipment should be anticipated. The largest possible impact would occur following complete failure of a hot feed cylinder containing liquified $UF_6$ (NRC 1994).

ES&H effects to workers are similar in both the centrifuge and gaseous diffusion types of plants. In the centrifuge plant the dominant ES&H effects to workers would result from maintenance and repair of centrifuges, and in the gaseous diffusion plant the dominate ES&H effects would be to workers involved in the maintenance and repair of compressors. Since the number of active components in the centrifuge plant (centrifuges)is about 1/3 those (compressors) in a gaseous diffusion plant, given a comparable equipment reliability, the ES&H effects should be lower in the centrifuge plant.

#### Transportation

The transportation of radioactive materials is regulated under 10 CFR Part 71 and 49 CFR. $UF_6$ cylinders are frequently transported to and from the GDPs in accordance with existing procedures (NRC 1994).

Disposal

All CEC-generated solid radioactive wastes will be Class A low-level waste (LLW) as defined in 10CFR 61. It is estimated that the CEC will generate 1,110 kg of RCRA hazardous wastes per year (about 650kg/yr of hazardous and 460kg/yr of mixed waste). Under federal regulations, a facility that generates less than 100 kg/month is conditionally exempt.

Solid waste would be collected and transferred to authorized treatment or disposal facilities offsite (NRC 1994).

All liquid effluents, with the exception of storm water, would go to treatment. The liquid effluent fallouts will be regulated by a National Pollutant Discharge Elimination System (NRC 1994).

A.2 Siting Factors

Siting standards for centrifuge enrichment plants are covered in NRC licensing regulations for the possession and use of source material. According to 10 CFR Part 40.31, to obtain a license to possess and use source material, such as depleted uranium, an application must be filed with the NRC at least 9 months prior to start of construction, accompanied by any Environmental Report required pursuant to 10 CFR Part 51. The Environmental Report must describe the environmental impacts of the construction, operation, and decommissioning of the plant and include the status of compliance with all applicable federal, state, regional, and local regulations for environmental protection, including zoning and other land-use restrictions. Under 10 CFR Part 40, the license application for possessing and using source material must provide installation information pursuant to 10 CFR Part 75.11, which, for siting, includes identifying the geographic location of the plant.

The NRC staff concluded that the LES facility (NRC 1994) could be constructed and operated with small and acceptable impacts on the public and the environment (NRC 1994).

A.3 Public and Worker Safety

The facility would be operated in accordance with all regulations for the protection of the public and workers (NRC 1994).

## B. WASTE MANAGEMENT

B.1. Waste Storage, Transportation, Treatment, or Disposal

Operation of the centrifuge facility would result in the annual production of depleted $UF_6$. The depleted UF6 would be stored onsite in cylinders and would have small impact while in storage. A proposed license of the centrifuge facility would require the removal of the depleted $UF_6$ from

the site within 15 years of initiating enrichment or after production of no more than 80,000 metric tons of depleted $UF_6$, whichever occurs first (NRC 1994). Thus, no later than 15 years after commencement of operations, the depleted tails will have to be transported. For operation of the CEC, the NRC established an inventory and time limits for onsite storage of DUF. The NRC could, however, establish different limits for onsite storage of DUF at a another site. Due to the reactivity of depleted $UF_6$ with water, long-term disposal of the material will require conversion to a more chemically stable form. The potential effect of depleted $UF_6$ storage at the site is exposure of workers to gamma rays, bremsstrahlung, and x-rays due to direct and atmosphere-reflected transmission of radiation (NRC 1994).

## C. COSTS

LES estimates the capital cost of the centrifuge plant, including interest, property tax, and transmission facilities, to be approximately $855 million. Escalation, capitalized interest, contingency, depleted $UF_6$ disposal, decommissioning, and replacement centrifuges raise the total investment to about $1.6 billion. At full output, CEC would produce 1.5 million separative work units (SWUs) of enriched uranium per year. Based on a 1990 market price of $110/SWU, the value of the uranium enrichment service would be approximately $165 million/year. (Note: This estimate is not based on using depleted $UF_6$ as feed material). All values are expressed in 1990 dollars. The impact of costs associated with using depleted $UF_6$ as a feed material is not available at this time (NRC 1994). However, because of the lower assay of U-235 in the feed (about 1/3 lower) the cost per SWU will be increased.

When compared to the gaseous diffusion process, the amount of electrical energy required by the centrifuge process to produce one SWU is approximately 1/50th of the energy required for gaseous diffusion technology.

## D. TECHNICAL MATURITY

The centrifuge enrichment process is a standard industrial practice which has beenused predominantly by other countries for many years. The proposed CEC facility, if built, could be running within six years (NRC 1994).

## E. SOCIOECONOMICS

### E.1. Employment

Construction of a centrifuge facility would benefit construction employment, operational employment, and indirect employment related to both. For example, the CEC plant would employ an average construction work force of about 200 per year for 6 years and an average operations work force of about 180. Average annual earnings (including benefits) are estimated to be about $37,000 for construction workers and $44,400 for operations workers (1990 dollars) (NRC 1994).

E.2. Public Acceptance

The local population would fill the lower skill jobs. Highly skilled positions (e.g., health physicists, chemical engineers, etc.), will mostly be filled by individuals brought in from existing high-technology chemical and nuclear facilities in other parts of the U.S. A significant amount of migration for the high-technology jobs can be expected (NRC 1994). However, the facility's low environmental impacts, together with employment opportunities, would be expected to result in acceptance by a host community.

E.3. Local/Required Development

Construction and operation of the facility are likely to increase both housing and land prices because of increased demand. The magnitude of the benefit is difficult to quantify but is not negligible.

## REFERENCES

1. Nuclear Regulatory Commission. 1994. *Final Impact Statement for the Construction and Operation of Claiborne Enrichment Center, Homer, Louisiana,* NUREG-1484, Vol.. I.

2. Hertzler 1994 *Depleted Uranium Disposal Options Evaluation,* EGG-MS-11297.

3. Carter, Steven T. 1994Ohio Valley Regional Development Commission, Economic Development Commission to the S9RFRS6324[1].

4. T.J. Hertzler March 1994 *Depleted Uranium Management Alternatives.*

[1]RFR Submitted #11

# INFORMATION PACKAGE
# I1/I2

# Shielding Using DU Metal
# or
# Uranium Carbide

This information package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on depleted $UF_6$ technologies or applications currently under consideration by the Department. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; they are intended to provide sufficient information to assist the Independent Technical Reviewer.

# *SHIELDING USING DU METAL OR URANIUM CARBIDE*

## 1. OVERVIEW

This information package briefly describes an application for depleted uranium (DU) metal or uranium carbide (UC) as shielding materials for storing, transporting, and disposing of commercial spent nuclear fuel (SNF). It also provides supplemental data on environment, safety, and health; waste management; cost; technical maturity; and socioeconomics, to assist in the evaluation of a Request for Recommendation submittal from M. Strauch (RFR No. 2).

Large-scale applications for DU or UC as shielding materials include SNF containers, such as the multipurpose canister (MPC) and the multipurpose unit (MPU) concepts sponsored by the U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM), and onsite SNF storage systems. These applications will be discussed in detail. Additional applications for DU or UC as shielding materials include radiopharmaceutical containers and Ducrete (see Information Packages B1 and B2).

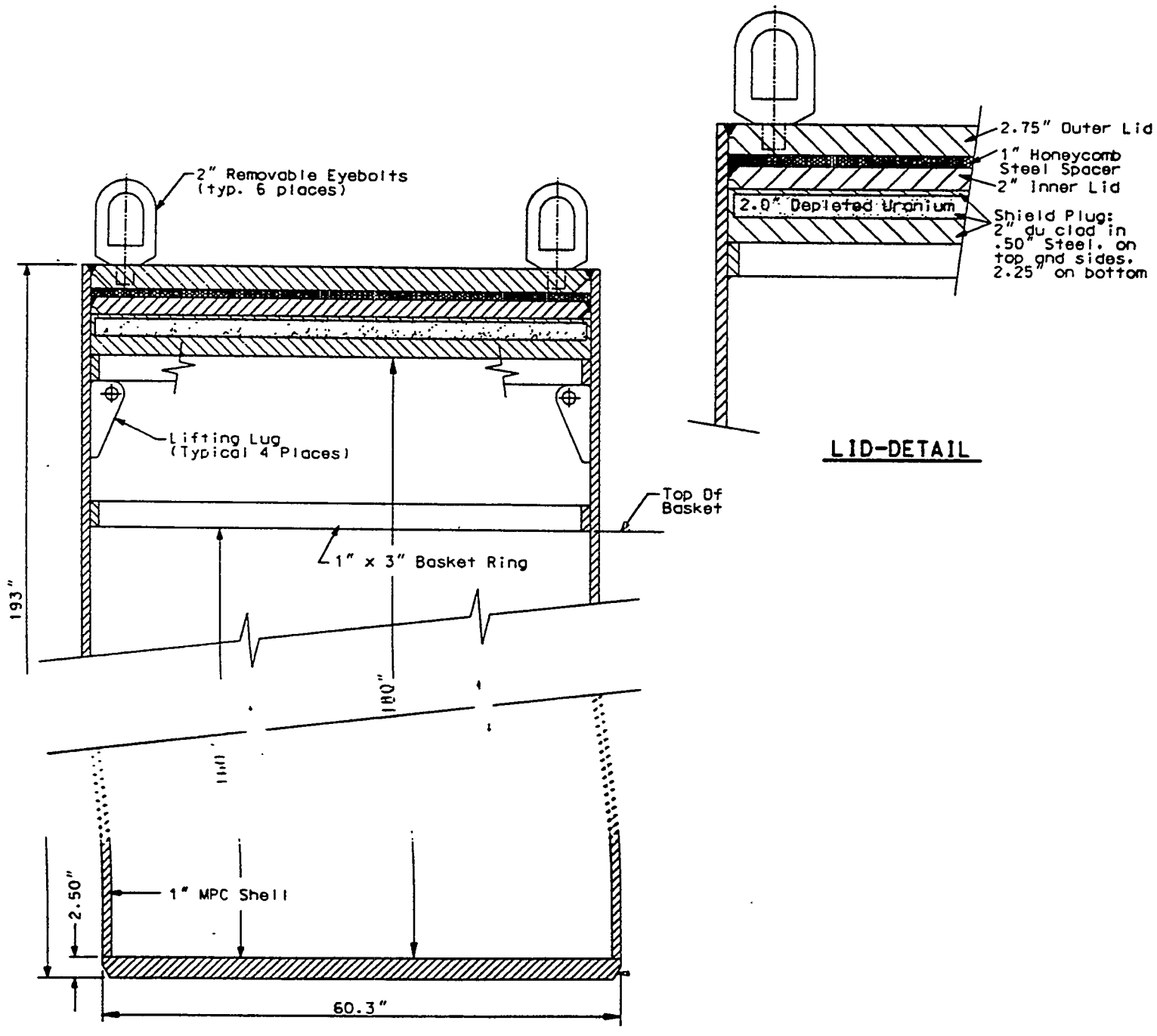
SNF Containers

The MPC concept is a triple-purpose, sealed, metallic container that can be used for storing, transporting, and disposing of SNF. Multipurpose canisters have a single shell with two lids that are welded to provide a dry, inert environment for the SNF. Each MPC is contained within an additional package (e.g., transportation cask or transfer cask) designed uniquely for the system functions of storage, transportation, and geologic disposal (DOE 1994). Preliminary package designs for a large 125-ton MPC (Figure 1) and a small 75-ton MPC have been conceptualized by the DOE-OCRWM (Hertzler and Nishimoto 1994).

Each MPC consists of a cylindrical shell with two lids, an SNF basket, and a shield plug. The basket provides structural support for the SNF assemblies and serves as a conduit for the transfer of the heat generated by the SNF into the MPC shell. The cylindrical shell provides structural support for the basket and ensures the geometric stability of the basket. The cylindrical shell and inner lid provide a primary containment boundary that prevents the release of radioactive material from the SNF. The outer lid provides radioactive shielding, secondary containment, and a redundant seal.

Depleted uranium is being considered as a shielding material for the MPC shield plug and the transportation cask body (59 FR 53442). As shown in Figure 1, the lid is 8 inches thick, and comprises a 2.75-inch outer lid, a 1-inch honeycomb steel spacer, a 2-inch inner lid, and a 2-inch DU shield plug, clad in steel (DOE 1994). As shown in Figure 2, it could also be used as a gamma shielding material for the metal annulus in the transportation cask (Hertzler and Nishimoto 1994).

**Figure 1 125-ton Multi-Purpose Container (MPC)**



The MPU system is an alternative for SNF handling in which SNF assemblies are placed in a sealed, multipurpose cask that is optimized for storage, transportation, and disposal. Once the assemblies are placed in the MPU, they do not need to be removed. The MPU system includes a cask with an inner sealed canister, similar to an MPC (Figure 3). The canister contains the SNF geometry and provides criticality control and SNF containment. The MPU is used for transportation, storage, and disposal (after permanent sealing). Two welded lids are used to seal the inner canister of the MPU, and a bolted lid is placed on the outer cask during the storage and transportation phases. Conceptual designs have been developed for two sizes of MPUs, a 125-ton MPU and a 90-ton MPU. The 125-ton MPU can accommodate 21 pressurized water reactor (PWR) assemblies or 40 boiling water reactor (BWR) assemblies (DOE 1994). As with the MPC, DU will be used as a shield plug in the MPU outer lid.

SNF Storage Systems

The U.S. Nuclear Regulatory Commission (NRC) has licensed several SNF storage systems for use at specific commercial nuclear power facilities. There are many types of dry storage technology currently in use or proposed by various vendors. In general, these include aboveground free-standing casks; aboveground free-standing dry storage buildings; and inground holes or wells with or without casks (DOE 1995). One example of an aboveground, freestanding cask design is the VECTRA NUHOMS, which utilizes a horizontal dry storage cask system for SNF (Figure 4). The NUHOMS-7P and NUHOMS-24P designs are licensed for and used at the Robinson, Oconee, and Calvert Cliff nuclear power plants. Both of these designs use concrete for gamma and neutron shielding. Conceptually, DU metal or UC could be incorporated into SNF storage system designs to provide shielding.

## 1.1 Process Description

The depleted uranium hexafluoride ($UF_6$) would have to be converted to uranium metal or UC before it can be used as a shield material. Detailed information on the conversion process from depleted $UF_6$ to DU metal is provided in Information Packages 3, 4, and 5. Information Packages 10 and 11 provide descriptions of the conversion process from depleted $UF_6$ to UC. Brief descriptions of the fabrication methods that could be employed for DU metal and UC are provided below.

**Figure 2 Metal Annulus of Transportation Cask**

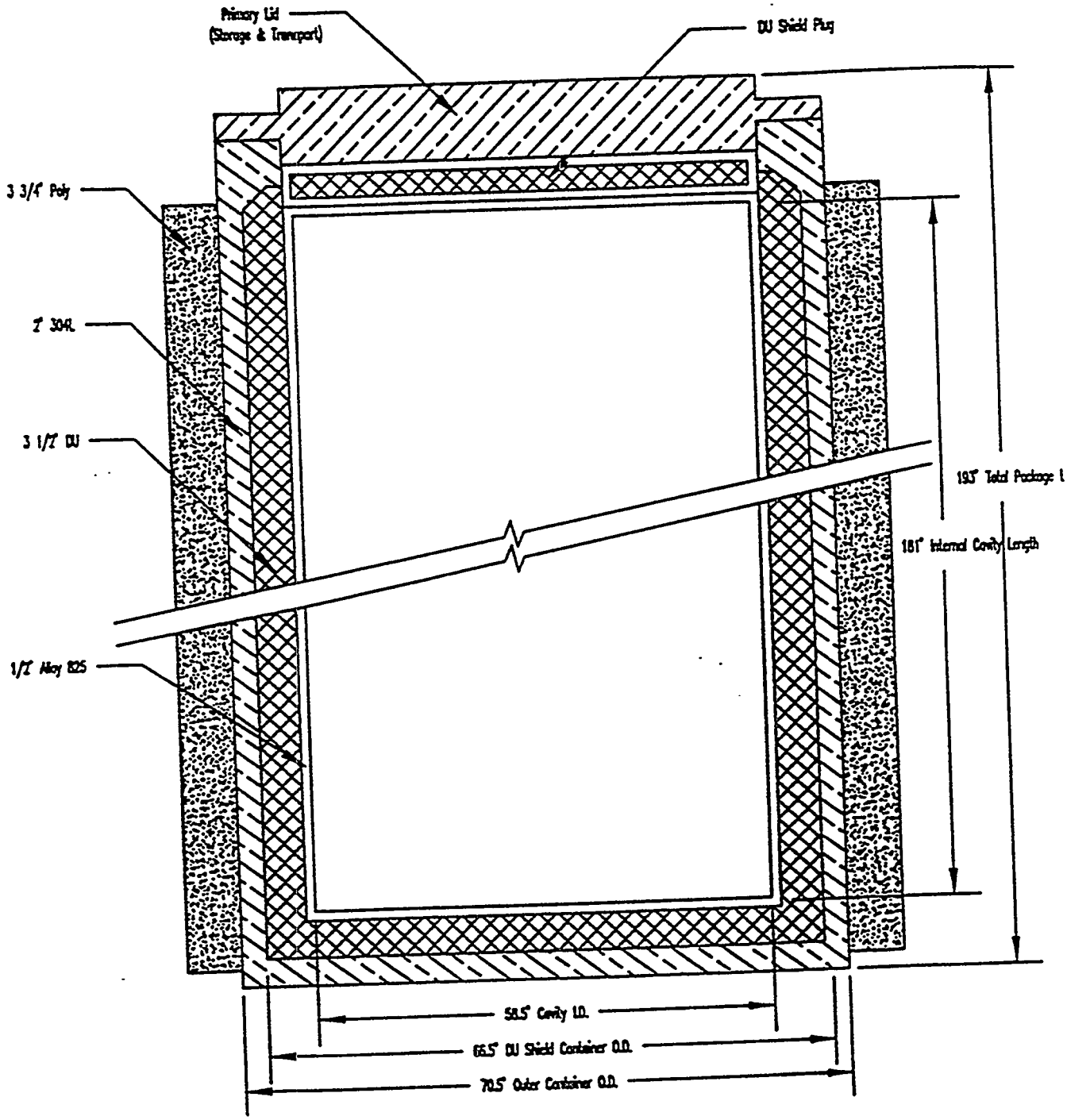


**Figure 3 125-ton Multi-Purpose Unit (MPU)**

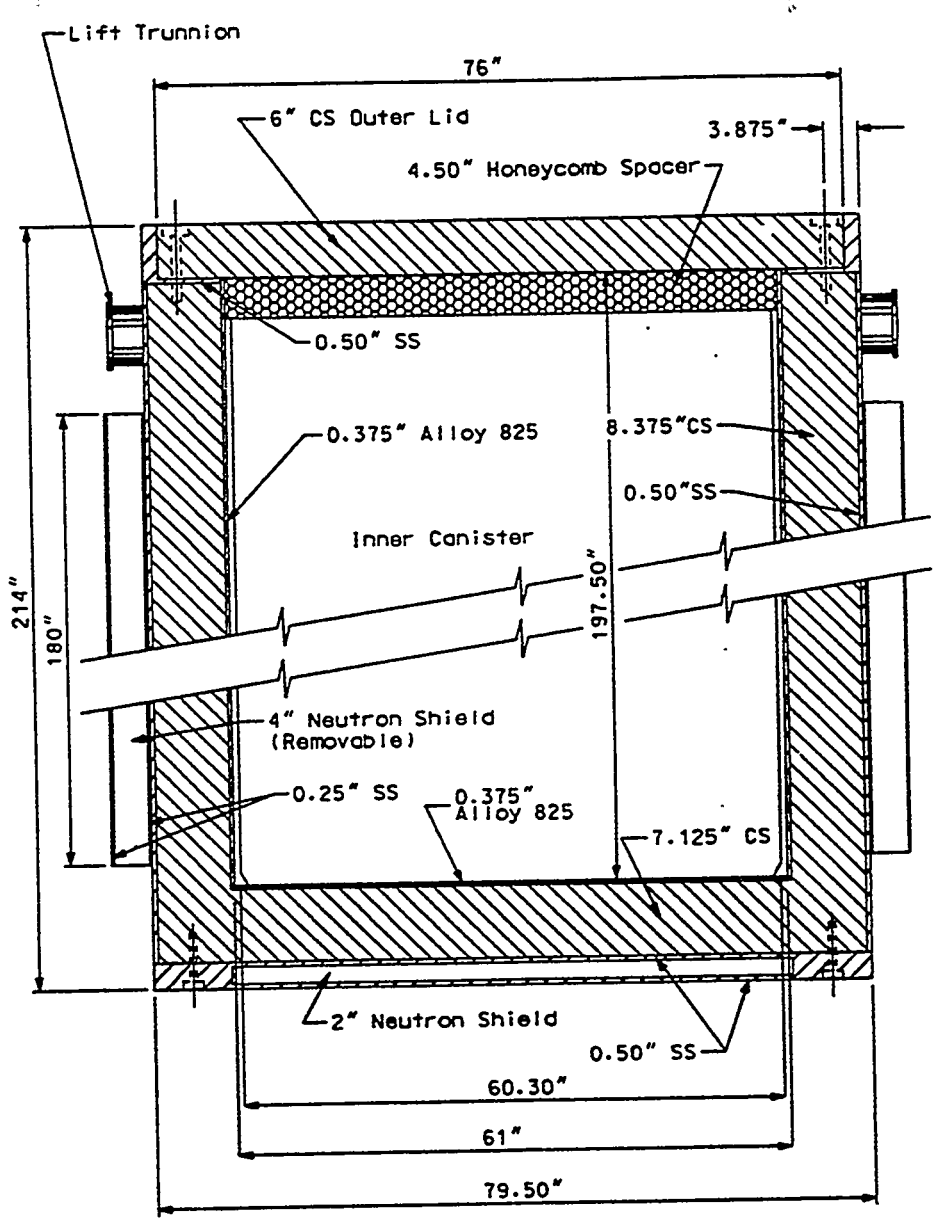
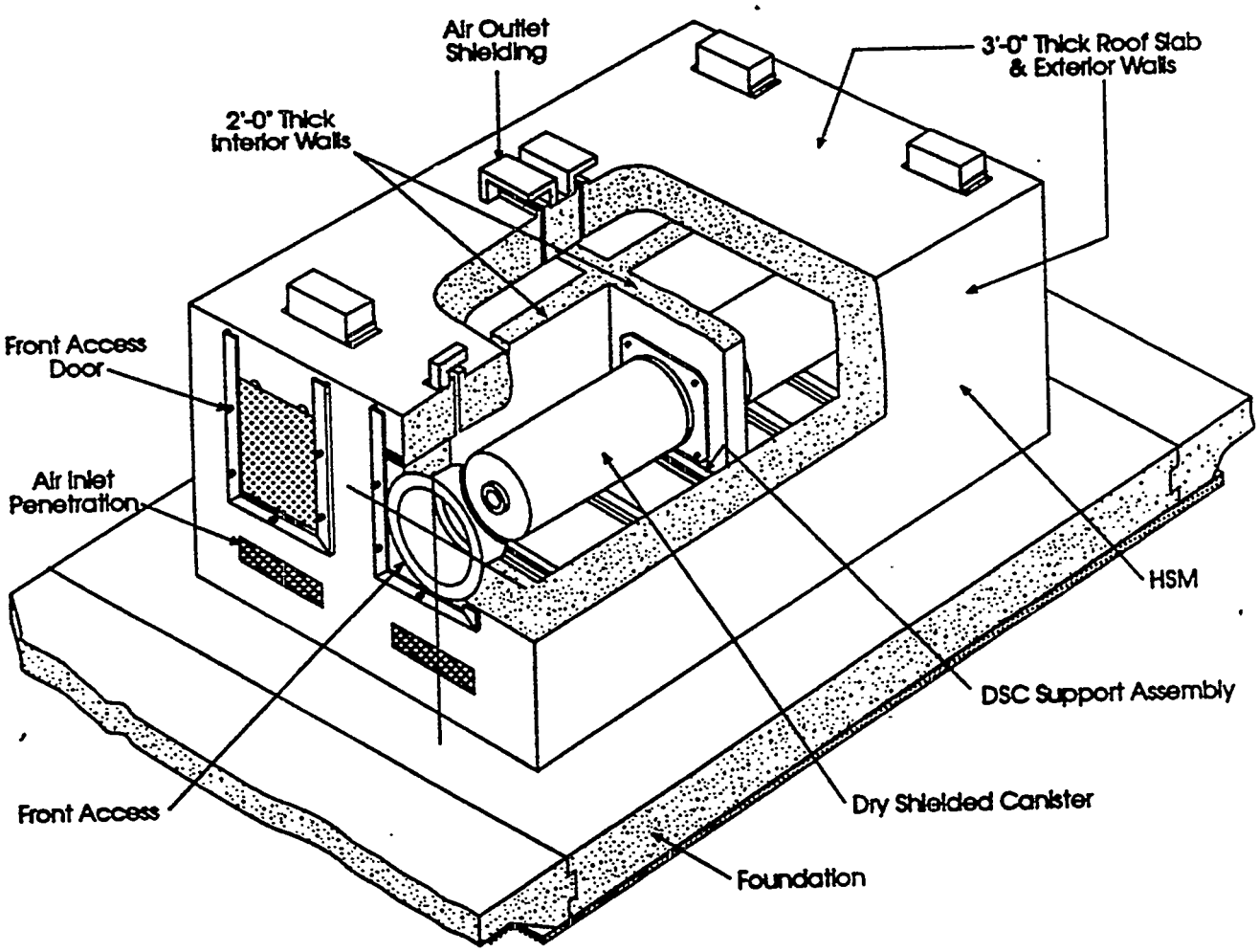


**Figure 4 VECTRA's NUHOMS 24-P Horizontal Storage Module**



DU Metal Fabrication Methods

There are two basic methods for producing annular shielding, such as for the SNF assemblies and other cylindrical containers. The DU metal shield portion of an SNF container could be fabricated by (1) casting interlocking rings or casting segments, or by (2) wrought forming into segments. Casting is generally considered to be the less expensive of the two methods. However, close tolerances and complex geometries are not easily obtained with cast materials. Wrought forming metal in segments has the advantage over casting in being able to achieve closer tolerances; however, it requires more initial treating, machining, and milling operations (Derrington 1993).

Assembly of interlocking cast rings to form the cylindrical vessel is generally accomplished by pinning the rings together and therefore requires less welding than segment assemblies. However, casting facilities are limited for large-diameter rings of the size required for a 125-ton container. Only two North American companies, Cameco Corporation (Port Hope, Canada) and Aerojet Ordnance (Jonesborogh, Tennessee), are known to be capable of casting large-diameter (greater than 40 inches) rings of DU metal. Other potential uranium metal producers and fabricators are limited to smaller diameters (40 inches or less) due to the size of commercially available graphite molds. Containers fabricated using wrought segments are not restricted in this manner. Based on the above considerations, fabricating DU metal shielded SNF packages from cast interlocking rings would appear to be preferable, with a minimum of milling and machining expected to be necessary (Derrington 1993).

To meet the purity specifications for fuel fabrication, the melting and casting of DU metal is performed under vacuum in graphite crucibles and molds[1]. The uranium metal derbies resulting from the Ames reduction process (see Information Package 3) are charged to a melting crucible, together with any alloying agents, and melted in an induction furnace at approximately 2,200°F. The molten metal is poured into a bank of cylindrical molds and allowed to cool for several hours under a partial shield vessel. A cast bottom end-plate would be welded to the cylindrical wall with a full penetration weld to complete the vessel configuration (Derrington 1993).

An alternative form of the shielding material would utilize uranium carbide. Uranium carbide shielding would probably use UC pellets or particles coated with silicon carbide and packaged into a metal annulus by vibratory methods. Multiple sizes would allow the achievement of very high densities. A bonding or thermal treatment may be used to hold the pellets or particles together (see Information Package F1).

[1]The purity requirements for fabricating DU metal shielding are not expected to be as rigorous as the specifications for uranium metal fuels.

## *EVALUATION FACTORS*

## A. ENVIRONMENT, SAFETY, AND HEALTH

Environment, safety, and health issues would be covered by existing federal, state, and local regulations for operations involving radioactive materials.

### A.1 Operations, Handling, Storage, Transportation, and Disposal

Materials that would be used in fabrication of DU metal or UC shielding are covered by Federal, State, and local regulations involving process safety, transportation, handling, storage, and disposal. Spent fuel storage cask designs, such as those for the MPC, would be licensed under 10 CFR Part 72, Subpart L (*Approval of Spent Fuel Storage Casks*).

Uranium is toxic to the kidneys, and high exposure to soluble compounds can result in renal injury. A concentration of about 1 μg/g of kidney tissue has been used as a guideline for controlling the chemical toxicity of uranium. In occupational situations, where inhalation is the primary concern and radiation dose limits are high, chemical toxicity is limiting for more soluble compounds and radiotoxicity is limiting for the insoluble compounds (Hertzler and Nishimoto 1994).

#### Transportation

In general, the transportation of radioactive materials is regulated under 10 CFR Part 71 (*Packaging and Transport of Radioactive Material*) and 49 CFR (*Transportation*). The MPC in combination with its respective overpack(s) will be required to meet the regulatory criteria set forth in 10 CFR Part 71. The MPU will also need to meet 10 CFR Part 71 regulations for transportation.

#### Disposal

Disposal of high-level radioactive materials is regulated under 10 CFR Part 60 (*Disposal of High-Level Radioactive Wastes in Geologic Repositories*) and 40 CFR Part 191 (*Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste*).

Consistent with the definitions for source material, the U.S. Department of Energy has historically treated depleted uranium as source material subject to regulation under the Atomic Energy Act of 1954, as amended. Depleted uranium, if ever declared a waste, would currently be classified as low-level waste. Disposal within a DOE low-level waste facility would be subject to DOE regulations. However, disposal of depleted uranium at a commercial facility would be subject to the NRC requirements imposed on the facility as a licensee (Hertzler and Nishimoto 1994).

### A.2 Siting Factors

Siting standards for DU metal or UC shielding fabrication plants would be covered in NRC licensing regulations for the possession and use of source material. According to 10 CFR Part 40.31 (*Application for Specific Licenses*), to obtain a license to possess and use source material, such as depleted uranium, an application must be filed with the NRC at least 9 months prior to the start of construction, accompanied by any Environmental Report required pursuant to 10 CFR Part 51 (*Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions*). The Environmental Report must describe the impact to the environment from the construction, operation, and decommissioning of the plant, including the status of compliance with all applicable federal, state, regional, and local regulations for environmental protection, including zoning and other land-use restrictions. Under 10 CFR Part 40, the license application for possessing and using source material must include installation information pursuant to 10 CFR Part 75.11 (*Installation Information*), which for siting, includes identifying the geographic location of the plant.

Onsite use of SNF storage systems at nuclear utilities would require compliance with 10 CFR Part 72.

### A.3 Public and Worker Safety

Public and worker safety would be addressed by the material license for operating the DU or UC shielding fabrication plant. In general, fabrication process hazards include machining, which can generate DU metal or UC powder that can be inhaled by workers, and handling of DU metal or UC fines. Uranium carbide forms solid solutions with uranium dioxide ($UO_2$) and uranium nitride. The carbides are stable only in dry air at room temperature, but the stability is greatly enhanced by the TRISO coatings (see Information Package F1). Uncoated carbides react rapidly with water or steam, so they should not be allowed to come into contact with moist air (Benedict et al. 1981).

## B. WASTE MANAGEMENT

### B.1 Waste Storage, Transportation, Treatment, or Disposal

There do not appear to be any unique waste management concerns with the fabrication of DU metal or UC shielding material. Wastes generated in the fabrication of DU metal or UC shielding material should be limited to minor losses during machining and in the cutting fluid recycle (Derrington 1993).

### B.2 Recycling Potential

Any recycling potential would be realized in the use of DU metal or UC as a shielding material instead of disposing it as low-level waste. In particular, DU metal significantly reduces the size

and weight of the MPC or MPU container compared to similar containers fabricated with concrete, while simultaneously allowing for reuse and disposal of DU.

## C. COST

The cost estimates presented here are for the MPC/MPU concepts and the horizontal dry storage cask design.

### C.1 Capital Costs, Annual Operations, and Maintenance Costs

SNF Containers

Table 1 shows the cost estimates developed by the DOE-OCRWM for MPC fabrication alone. The total fabrication cost is approximately $5 billion (DOE 1994). These costs assume placement in a monitored retrievable storage (MRS) facility. Costs would drop slightly in the non-MRS case.

**Table 1. Cost Estimates for MPCs (1993 dollars)**

| *COST ITEM* | *QUANTITY*[a] | *COST* |
|---|---|---|
| Large PWR MPC | 5,768 | $2,042 M |
| Large BWR MPC | 3,333 | $1,440 M |
| Small PWR MPC | 698 | $200 M |
| Small BWR MPC | 1,367 | $377 M |
| TOTAL COST | | $4,059 M |
| TOTAL COST (w/25% contingency) | | $5,074 M |

(Source: DOE 1994)
[a]Represents the number of MPCs required for storing, transporting, and disposing of commercial SNF.

For MPU systems, DOE estimated a total fabrication cost (in 1993 dollars) of approximately $12.6 billion (DOE 1994).

SNF Storage Systems

On a per canister basis, the approximate unit capital cost range for a horizontal dry storage cask is $400,000 to $500,000. The estimated absolute maximum total annual operating cost is $3.7 million for a storage array of up to 100 canisters (DOE 1995).

## C.2 Product Value/Facility Salvage

For MPCs and MPUs, DOE estimates a sales potential of approximately $2.9 billion and $2.05 billion, respectively. However, using DU metal in MPCs/MPUs, overpacks, and storage systems would reuse the material and avoid storage and disposal costs (and potential liabilities).

## D. TECHNICAL MATURITY

SNF Containers

The DOE-OCRWM is currently evaluating the feasibility of MPCs and has announced its intent to prepare an Environmental Impact Statement (EIS) for the Fabrication and Deployment of a Multi-Purpose Canister (MPC) System for the Management of Spent Nuclear Fuel (59 FR 53442). The technology for fabricating containers is developed and is standard industrial practice for other materials. The use of DU metal or UC as a nonstructural shielding component in a SNF container is feasible because DU metal has been used to provide gamma shielding in SNF transportation casks.

SNF Storage Systems

Spent nuclear fuel storage systems are standard technology. Several SNF storage systems for use at specific commercial nuclear power facilities have been licensed by the NRC (DOE 1995). Some design work is anticipated to incorporate DU metal or UC into existing designs.

## E. SOCIOECONOMICS

### E.1 Employment

Actual employment data for fabrication of DU metal or UC shielding for MPCs are not available at this time.

### E.2 Public Acceptance

No formal evaluation of public acceptance has been made at this time. Some limited public resistance to the siting and licensing of a DU metal or UC shielding fabrication plant could be expected.

### E.3 Local/Regional Development

Local and regional development resulting from construction and operation of an MPC fabrication plant cannot be measured at this time.

## REFERENCES

Benedict, M., Pigford, T. H. and Levi, H. W. 1981. *Nuclear Chemical Engineering*, McGraw-Hill, Inc.

Derrington, S. 1993. Martin Marietta Energy Systems, Inc. *DOE Capabilities on Depleted Uranium Conversion and Fabrication* (Presented at the Reuse and Recycle of Depleted Uranium Workshop).

Hertzler, T. J. and Nishimoto, D.D. 1994. *Depleted Uranium Management Alternatives.* (EGG-MS-11416).

Strauch, M. 1994. Letter to C. Bradley, Jr., DOE.[2]

U.S. Department of Energy (DOE). 1995. *Draft Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel.* DOE/EIS-0218D.

U.S. Department of Energy (DOE). 1994. *Multi-Purpose Canister System Evaluation: A Systems Engineering Approach.* DOE/RW-0445.

[2]Request for Recommendation #2.

# INFORMATION PACKAGE
# J1

# Dense Material Applications (DMA)

This Information Package was prepared to supplement the technical information contained in the responses to the Department of Energy's Request for Recommendations and to provide technical information on Depleted $UF_6$ technologies or applications currently under consideration by the Department of Energy. All efforts have been made to provide only technical information and not professional opinion. The information packages do not contain all known technical information; it is intended to provide sufficient information to assist the Independent Technical Reviewer.

# Dense Material Applications (DMA)

## 1. OVERVIEW

This information package briefly describes dense material applications (DMA) of depleted uranium (U) metal derived from depleted uranium hexafluoride ($UF_6$). It also provides supplemental data to assist in the evaluation of Request for Recommendation submittals.

Several respondents to the RFR proposed using depleted uranium metal in dense material applications: Quapp (1994), Montford (1995), and McWilliams (1995).

### 1.1 Conversion of $UF_6$ to Uranium Metal: Brief Process Description

The depleted $UF_6$ requires conversion to uranium metal before use in dense material applications. This can be achieved through an improved AMES process (Information Package 3), a plasma method (Information Package 4), or continuous metallothermic reduction (Information Package 5).

### 1.2 Proposed Uses of Depleted Uranium Metal

Table 1 summarizes dense material applications. DMAs related to shielding are described in Information Packages I1 and I2, *Shielding*.

*A. Energy Storage Flywheels*

Depleted uranium metal could be used in kinetic energy storage devices such as flywheels. Preliminary studies at INEL indicate a 20% improvement in efficiency over conventional materials (INEL 1994).

*B. Vehicle Ballast and Counterweights*

Depleted uranium metal could be used on ships, submarines, large land vehicles, or airplanes as ballast or counterweights. Options include cast shapes and contained powders. Uranium carbides may also be used for this application (INEL 1994).

*C. Munitions*

A proven existing technology takes advantage of the high density of depleted uranium to increase the effectiveness of munitions. This option applies to munitions ranging from small caliber handguns to 16-inch shipboard guns (ARDEC 1987).

## Table 1. Proposed DMA Uses for Depleted Uranium

| Use | Advantages | Disadvantages |
|---|---|---|
| A. Energy Storage Flywheels | Higher energy transfer and storage efficiency than other alloys | Potential worker or environmental exposures during maintenance or operation |
| B. Vehicle Ballast and Counterweights | Takes up less space for equal mass<br><br>Depleted uranium carbides can also be used | Potential worker or environmental exposures during maintenance, operation, or accident<br><br>Disposal problems once vehicle or equipment is retired |
| C. Munitions | Significant improvement in munition penetration and effectiveness due to the increased mass<br><br>Proven existing technology | Documented worker and environmental exposure at point of impact<br><br>Uncertain market due to military downsizing |
| D. Drilling | Significantly improved drilling operations due to the increased mass | Potential worker or environmental exposures during maintenance, operation, or accident.<br><br>Potential contamination of drilled material |
| E. Armor | Significant improvement in protection against munitions<br><br>Proven existing technology | Documented worker or environmental exposure at point of impact due to ejecta from armor |

(Note: The information in this table is drawn from the references listed in the text of Section 1.2.)

*D. Drilling*
The relatively high density of depleted uranium metal could prove useful in drilling collars, weights, and penetrators (shaped charges) (DOE 1994).

*E. Armor*
Depleted uranium metal could also be founded, milled, and formed, in its pure state or as an alloy, into vehicle armor or bunker hardening materials (ARDEC 1987, DOE 1994).

2 Depleted $UF_6$ Consumption

In addition to existing depleted $UF_6$ stockpiles (~560,000 metric tons), there is an estimated 5,000 metric tons of U metal in storage (DOE 1993).

**Table 2. Potential Annual Depletion of $UF_6$**

| Proposed Depleted Uranium DMA Uses | Potential Annual Use of $UF_6$ (metric tons) |
|---|---|
| 1. Energy Storage Flywheels | Not thoroughly evaluated |
| 2. Vehicle Ballast and Counterweights | Not thoroughly evaluated |
| 3. Munitions | 22-100 |
| 4. Drilling | 10,000-40,000 |
| 5. Armor | 2,500-1,600,000 |

(DOE 1993, DOE 1994)

# 2. EVALUATION FACTORS

## A. ENVIRONMENT, SAFETY, AND HEALTH

Uranium is a toxic element with the potential for acute chemical effects on the kidneys. Its retention time in the body far exceeds the time needed to injure the kidneys. For a given bodily intake rate, all commonly used storage forms of depleted uranium, with the exception of $UO_2$, reach chemical threshold limits well before radiological threshold limits are reached. Uranium metal dust can be produced in normal atmospheric conditions by oxidation and thermal expansion. However, if the uranium metal is properly clad with other metals, as is done with current armor applications, there will be no significant risk from inhalation or ingestion unless the U metal is damaged (ACSTA 1989).

The radiological hazards of depleted uranium metal are less than those of naturally occurring geologic formations of uranium.

Normal Operations

Uranium milling and forming produce scrap and dust that would be controlled to safe levels. Waste oils and lubricants may also become contaminated with uranium. If the uranium metal is used to make alloys, foundry-related wastes (e.g., slag, resins, etc.) will be generated. These materials can be pyrophoric under certain conditions.

For munitions, armor, and drilling applications, use of uranium results in the spread of debris and dust clouds, leaving contaminated soil and water.

For flywheels and ballast and counterweight uses, uranium dust could be formed if the material is mishandled or abraded.

Permitting (Siting Factors)

Currently, there are four operational facilities in North America (located in Massachusetts, Tennessee, South Carolina, and Port Hope, Canada) that can found, mill, and form depleted uranium metal, and five facilities with limited capabilities to form the metal (located in Idaho, Colorado, Tennessee, California, and New Mexico). If regulatory requirements become more stringent, additional permitting may be required.

## B. WASTE MANAGEMENT

For founding, milling, and forming operations, the scrap depleted uranium material requires disposal in accordance with regulations. The by-products, such as slag and lubricants may be disposed of in landfills if the residual radioactivity is less than 35 picocuries per gram of material.

Several studies indicate that significant contamination of the soil and water occurs when depleted uranium metal munitions impact an object or surface, or when any munition impacts depleted uranium armor (AFRRI 1993, GAO 1993, SAIC 1989). Studies are needed on effective and cost-efficient methods to clean up the contaminated equipment, soil, and water. The long-term effects of such contamination also require evaluation.

For all dense materials applications, a primary consideration is the disposal of the uranium metal at the end of the service life of the vehicle or equipment. The options include recycling, reselling, or final disposal of the uranium metal. Decontamination of impact areas and disposal of low-level wastes may be an additional consideration for munitions, drilling, and armor applications.

## C. COSTS

The costs for founding, milling, or forming the uranium metal depend on the specific processes used and the desired product. Potential sources of cost include (Martin Marietta 1994, SAIC 1994)

- founding of the uranium metal to form alloys;
- casting or molding;
- milling;
- forming;
- grinding and precision lathing; and
- bonding with other materials.

The cost of converting depleted $UF_6$ to uranium metal and casting it into a shape is estimated to be $11/kg uranium (Technics 1993).

Additional facilities will need to be built in order to meet the product demand if some of the suggested DMA uses are implemented. At a minimum, NRC licensing of facilities manufacturing the depleted uranium would be needed. Additional security and control may be needed for military applications.

## D. TECHNICAL MATURITY

Uranium metal founding and milling processes are well established.

## E. SOCIOECONOMICS

Employment

Employment figures cannot be estimated until the scope of DMA uses is more clearly defined.

Regional Development

If existing facilities are used for uranium metal founding and milling, the impact on employment should be minimal. This would also have a minimal impact on housing, schools, and infrastructure. Development of new facilities would result in regional growth, but the scope of DMA uses needs to be more clearly defined before the regional impact can be estimated.

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